BASIC PHYSICS FOR PILOTS AND FLIGHT CREWS

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FOR PILOTS and FLIGHT CREWS

By

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Preface

The purpose of this book is to teach the fundamentals of physics as a preparation for Meteorology, Theory of Flight, and Engine Operation. It is designed to meet the requirements of primary flight training or air cadet training.

In a very condensed course there is always danger that some students will become proficient "lesson learners." Thus a student who has learned that acceleration is "the rate of change of velocity" or "the change of velocity per unit of time" may become confused when acceleration is defined as "change of velocity divided by time." The student should train himself to recognize the equivalence of slightly different expressions of the same fact. However, in many instances the student must master and adopt the method that has been found most satisfactory and that has become generally accepted.

Because graphic solutions are required in many of the exercises, each student should have a scale graduated in centimeters and a protractor. This equipment is inexpensive and should be brought to every meeting of the class.

The student is urged to read each lesson several times. However, new ideas in physics are not mastered by reading alone. After studying a chapter or a part of a chapter, the student himself should draw the figures, solve the problems explained in the illustrations, and write out the definitions given in the chapter.

The definitions have been phrased and rephrased in an effort to make them clear, complete, and as brief as possible. All of the text must be completely mastered.

The content of this book has been used at the Texas College of Mines and at four other institutions. Suggestions from both instructors and students have led to modifications which are incorporated in this text. The author is very grateful to all who have checked and criticized his original notes.

Sincere thanks are due to Professor C. W. van der Merwe of New York University for valuable criticisms and suggestions; and also, for their generous help and advice, to three of the author's colleagues: Professor P. W. Durkee, Dr. Leon Camp (now at the Underwater Sound Laboratory, Harvard University), and Mr. Tom Barnes (now in war research at Duke University).

E. J. K.

Contents

Part One

Part Two

PART ONE

CHAPTER 1

Introduction

Science is taken from a Latin word meaning "to know" and thus would include all knowledge. At present, the word *science* is frequently limited to include the natural sciences, any one of which may be defined as "an ordered knowledge of natural phenomena and relations between them, supported as far as possible by experimental evidence and correlated and extended by reasoning and further experiment." The most important natural sciences are astronomy, physics, and chemistry, which are the physical sciences, and geology, botany, and zoölogy, which are the biological sciences. These sciences are not sharply separated from each other; they overlap considerably. Each of the other sciences makes some use of the methods and the equipment developed in the study of physics.

What is physics? Curiously enough no entirely satisfactory definition has ever been formulated. A definition of the science of physics should tell the beginner what physics is, and it should not make him depend upon intuition to find the meanings of terms used. The words "science of physics," as introduced into the English language, meant "to know nature," and had this broad meaning years ago when physics was taught by professors of natural philosophy. At present the meaning of "physics" is much more limited. Physics has been defined as "the study of matter and energy." Although this definition has been justly criticized, it at least enables us to make a start. However, it does not show the beginner

why physics has given us the telephone, the radio, the airplane, the refrigerator, and many other technical developments. Why has the present war of machines been called "the physicist's war"? Why did a thorough understanding of physics enable S. P. Langley to build an airplane which the Curtiss brothers flew after the gasoline engine had been developed? Another definition of physics is "a science to discover, describe, correlate, and explain facts of the inanimate world."

The main subdivisions of physics are **mechanics, heat, electricity and magnetism, sound, light, radioactivity, X-rays,** and **atomic physics.**

Meteorology may be defined as the science of the atmosphere, or as the study of weather, its changes, and its prediction. We do not know when man first began to study weather. Ancient writings contain many phrases that were used to predict weather changes. Some of these phrases can be justified by scientific considerations; others cannot. Aristotle (384 B.C.) is known to have made a study of weather.

Galileo (1564–1642) invented the thermometer and advanced the scientific study of weather. The invention of the barometer enabled the science to make a real start. The growth of meteorology was greatly speeded as a result of scientific advancements made during the first World War.

Meteorology may be considered a specialized branch of physics. It makes use of laws and theories of physics and of much of the experimental apparatus of physics. A thorough foundation in physics and mathematics is required in the training of a professional meteorologist.

Meteorology is of utmost importance in civil and military aeronautics. Much of the recent progress in meteorology is due to the demands of aviation for more accurate and longer-range predictions. Weather facts of importance to the pilot are:

1. Visibility.
2. Ceiling.
3. Icing.
4. Haze (solid particles).
5. Prevailing winds.
6. Wind considerations for taking off and landing.
7. Altimeter corrections.

The people of London complained when British newspapers were forced to discontinue weather reports because, without them, they were unable to know when they might be safe from air raids. Information as to weather conditions in England would be of extreme value to the Axis powers, both in planning attacks and in predicting the weather for the continent.

Informed of weather conditions, the pilot can plan his trip so as to avoid regions of very unfavorable weather. The pilot makes use of all the weather information he can get from professional weather forecasters. If complete weather forecasts could be made with perfect accuracy and far enough in advance, a pilot would not need much training in meteorology. However, it is much easier to predict weather for a certain locality a few hours in advance than to predict what will happen in the next 12 hours. Thus the pilot is often forced to be his own judge of weather conditions. In times of war, the regular weather forecasts for some regions are greatly hampered by the lack of observations from enemy-occupied territory. Then local and last-minute observations become especially important.

The Atmosphere

Atmosphere, taken from Greek words meaning *vapor sphere,* is the entire envelope of dry air and water vapor that surrounds the earth.

The *composition* of dry air is as follows:

78% nitrogen (serves to dilute the oxygen),
21% oxygen,

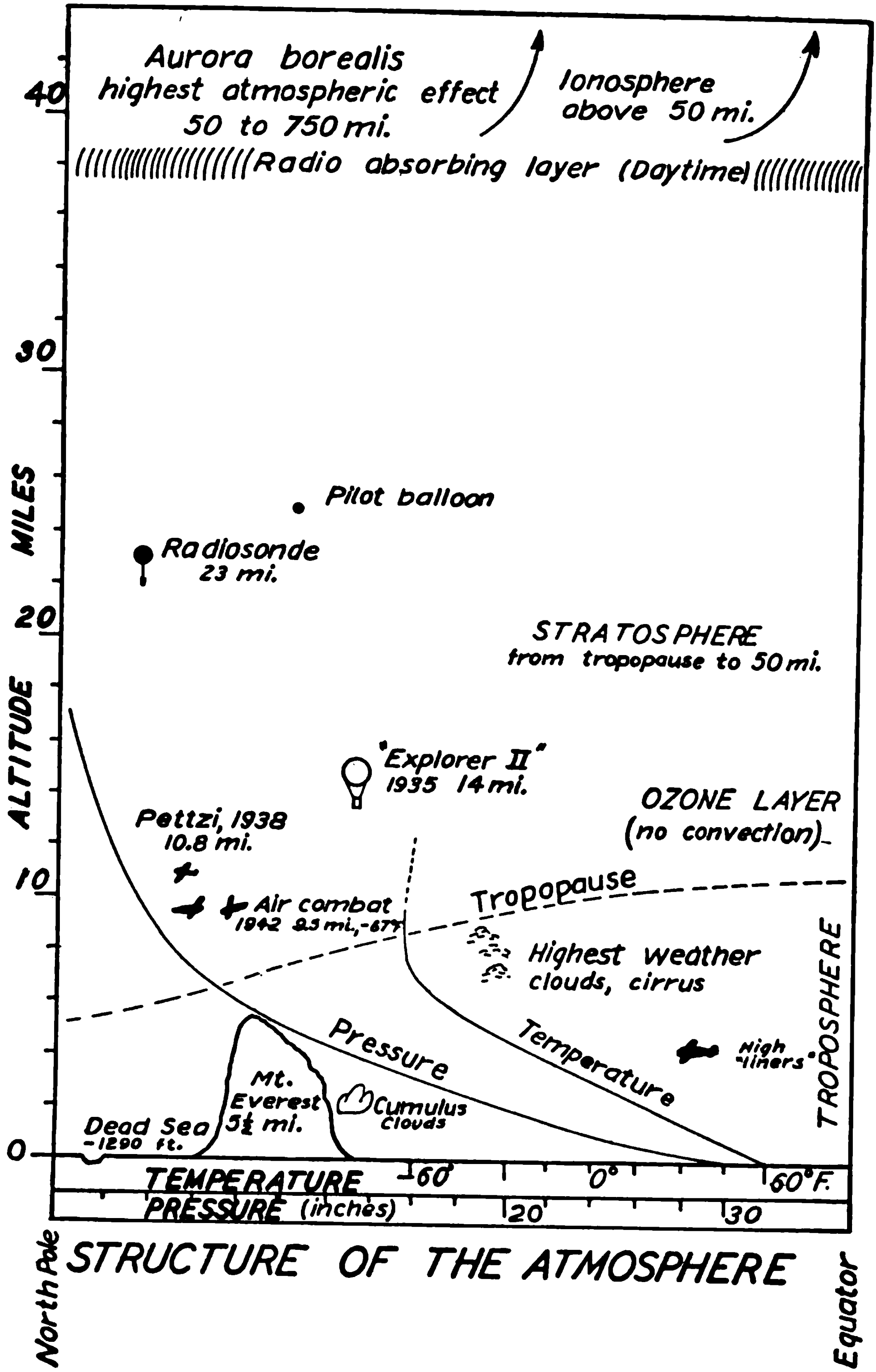

Aurora borealis
highest atmospheric effect
50 to 750 mi.
Ionosphere
above 50 mi.
Radio absorbing layer (Daytime)
40
30
20
10
0
ALTITUDE MILES
Pilot balloon
Radiosonde
23 mi.
STRATOSPHERE
from tropopause to 50 mi.
"Explorer II"
1935 14 mi.
OZONE LAYER
(no convection)
Pettzi, 1938
10.8 mi.
Air combat
1942 9.5 mi., -67°
Tropopause
Highest weather
clouds, cirrus
TROPOSPHERE
Pressure
Temperature
High liners
Mt. Everest
5½ mi.
Cumulus
Clouds
Dead Sea
-1290 ft.
TEMPERATURE -60° 0° 60° F.
PRESSURE (inches) 20 30
STRUCTURE OF THE ATMOSPHERE
North Pole
Equator

Figure 1

1% argon,
.03% carbon dioxide (exhaled by animals, consumed by plants, kept constant through absorption by oceans),
.01% of a mixture of neon, krypton, xenon, ozone, and hydrogen.

At sea level, about 1.2 per cent of the atmosphere is **water vapor,** but this percentage varies greatly. At all times the atmosphere holds myriads of microscopic particles of dust and salt in suspension. We shall see that these solid particles are of great importance.

Structure. (1) The atmosphere is elastic and easily compressible. (2) It has weight, about $\frac{1}{800}$ of the weight of an equal volume of water. One cubic foot weighs $\frac{62.5}{800}$ pounds, or 1.2 ounces. The atmosphere contained in an average college building weighs over a ton. (3) It exerts a pressure, about 14.7 pounds per square inch at sea level. To see how this pressure changes with altitude, refer to figure 1. (4) In our latitude, the temperature of the atmosphere decreases about 16°F each mile of altitude until a temperature of about −67°F is reached (figure 1). Above the equator, the decrease continues until at a height of about 11 miles the temperature is about −115°F!

Atmospheric Phenomena

The general circulation of the earth's atmosphere is shown in figure 2.

The bands indicated are drawn in the positions they occupy at an equinox, when the sun is overhead at the equator (about March 22 and September 22). The bands move to the south in winter and to the north in summer. These shifts account for the fact that some regions—for example, Southern California—have rainy winters and very dry summers.

The trade winds are stronger and steadier than the prevailing westerlies. The westerlies of the southern hemisphere are

more intense than those of the northern hemisphere because the southern hemisphere contains less land to interfere with the general circulation of the atmosphere. Thus the region from 40°S. latitude to 50°S. latitude became known as "the roaring forties."

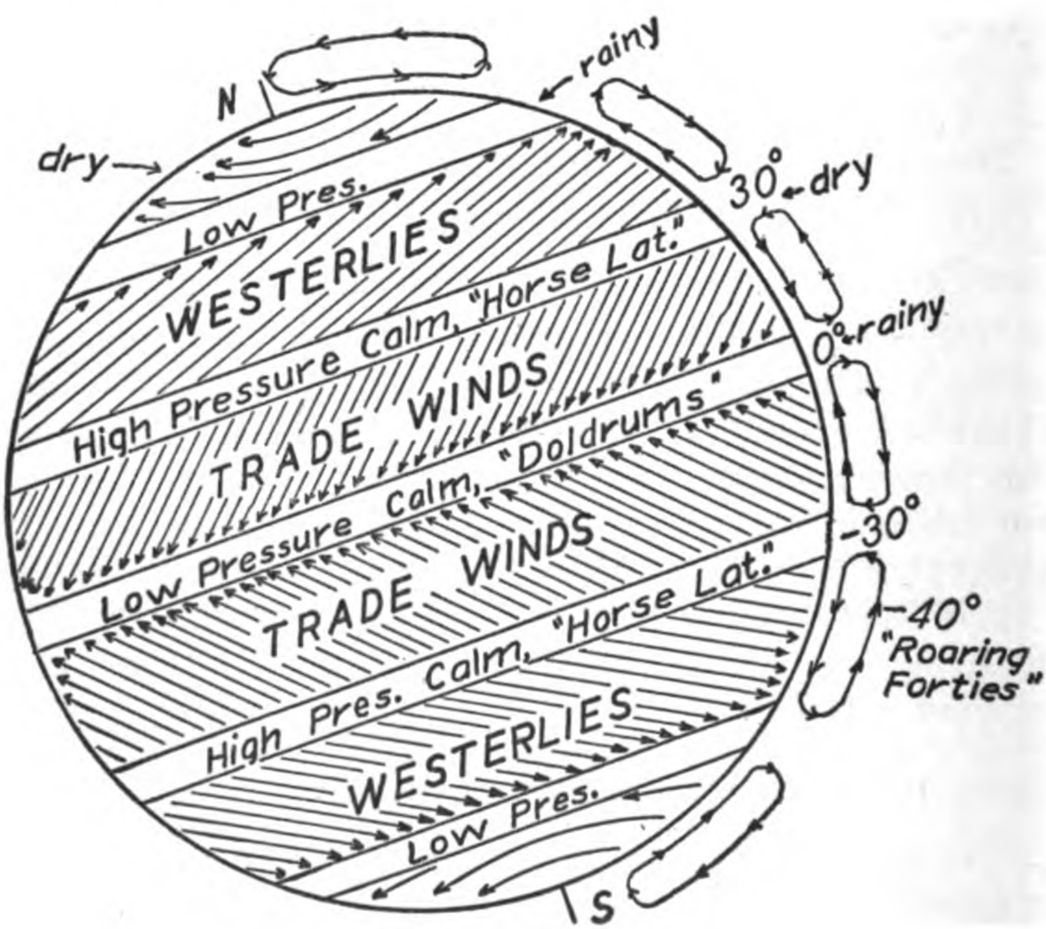


Figure 2

We can understand many facts of weather and climate if we remember prevailing wind directions. In our latitude, weather conditions travel from west to east, usually about 700 miles each day. However, the rate of travel is irregular and often a particular weather condition vanishes. A seaborne

invasion often can travel with a region of low visibility when going east. All of the first flights across the Atlantic were from west to east. The return is much more difficult.

A **cyclone** is a very large, gentle circulation of air whose center is a region of low pressure, cloudiness, and probable precipitation. The diameter of the entire cyclone is usually about 1,000 miles. In the northern hemisphere the winds of a cyclone travel in a counterclockwise direction. Cyclones are very common. Almost any daily weather map of the United States shows at least one cyclone. Cyclones are separated from each other by regions of high pressure. These regions of alternate low and high pressure travel from west to east because of the prevailing westerlies. A low pressure means that cloudiness and rain may be expected. A high-pressure region indicates fair weather. If an observer stands with his back to the wind, he may expect a low-pressure region somewhere to his left. If the low-pressure region is to the west, unsettled weather may be expected.

Hurricanes of the tropics and **tornados** of the temperate zone are smaller and more violent than cyclones. They are less important in weather forecasting.

Among the remaining atmospheric phenomena we may list land breezes, sea breezes, anticyclones or "highs," mists, fogs, clouds, dew, and electrical disturbances.

Functions of the Atmosphere

The atmosphere supports plant and animal life. Animals need oxygen and plants need carbon dioxide. The atmosphere decreases the diurnal variation of temperature. Because the moon has no atmosphere, its noons are terrifically hot and its nights are extremely cold. The atmosphere is fundamental in causing weather and climate. The atmosphere supports flight. No known type of flying craft could operate in a region devoid of atmosphere.

Solid Particles in the Atmosphere

Although carbon dioxide, water vapor, and solid particles exist in very small amounts in the earth's atmosphere, they are of tremendous importance to us.

Life would be impossible without carbon dioxide to feed plants or without water vapor to make rain. Furthermore, it seems unlikely that we could live if the atmosphere were entirely freed of solid particles. Some of them act as nuclei around which saturated water vapor condenses into droplets to form clouds. These nuclei are necessary for condensation. If they were not present, very little condensation, if any, would occur.

Although these particles are invisible, they produce important effects upon visibility. Together with water droplets, they produce an effect which is known as the **scattering of light.** Lord Rayleigh (1842–1919) and other physicists have made interesting and detailed studies of this effect. They show that when a light ray travels through an atmosphere which contains very small droplets or solid particles, some of the light is scattered out of the path of the ray. Relatively large particles scatter all colors equally, but the smallest particles and the smallest water droplets scatter blue light much more than they scatter red light. Some of the atmospheric phenomena caused by scattering and some of the practical applications of information about scattering are as follows:

1. Cumulus clouds are often very white because the water droplets which they contain are large enough to scatter all colors.
2. Tobacco smoke is blue because its particles are so small that they scatter mostly blue light.

3. The sun is especially red at sunrise because **at that** time the rays travel through the atmosphere for a greater distance than they do at noon.

4. The sky is blue because the light which comes to us from a clear sky has been scattered chiefly by small particles and molecules. The intense blue of the skies of Italy is attributed to the presence of very fine volcanic dust.

5. Yellow lights (sodium-arc) are used for lighting highways because this color, which is not far from the red end of the spectrum, is less completely scattered than other colors near the blue end of the spectrum.

6. Scattering reduces visibility. Distant mountains become obscured in a bluish haze and details become indistinct. In a deep haze, mountains may become entirely hidden.

7. In aerial photography for mapping and for large-scale surveying, most of the visible light is intercepted by a filter which permits **infra-red** (heat) rays to enter a camera provided with a special film which is sensitive to heat rays. Infra-red rays are not much affected by scattering. The rays travel great distances through fog and dust-laden air with very little loss, and thus sharp outlines are obtained in pictures of distant terrain.

Atmospheric scattering of light may be imitated by means of the lumirod.* This is a rod of transparent plastic material. If intense white light is allowed to enter one end of the rod and to traverse the length of the rod, the whole rod becomes luminous because much of the light is scattered at right angles to the main beam of light. The scattered light near the illuminated end of the rod has a faint blue color because blue light is especially subject to scattering by the material of which

* The apparatus may be purchased from manufacturers of physics equipment. If an alpha ray track apparatus (Central Scientific Co.) is available, it may be used in place of the cloud apparatus.

the rod is made. If we look directly at the other end of the rod, we see that the whole end glows with an orange color. Ordinary light, white light, is made up of all colors. If it is robbed, by scattering, of much of its blue components, the light that remains in the main beam becomes orange or red. These effects are similar to atmospheric scattering, which accounts for the blue of the sky and the redness of the sun at sunrise or sunset.

By means of a simple cloud apparatus,* it may be shown that clouds cannot be produced in an atmosphere which has been entirely freed of solid particles. In this apparatus, a rubber bulb from a battery tester is fitted over the mouth of a laboratory flask which has a side tube fitted to its neck. Some water and a little smoke are introduced into the flask through the side tube, and the tube is closed by means of an eraser of the type which fits over a pencil. The bulb is compressed and then quickly released. The air in the flask expands quickly and is cooled. As we shall see later, this is the common cause for the condensation of water vapor into a cloud of droplets. The whole bulb becomes filled with a cloud. Each droplet is the result of condensation of vapor around a microscopic solid particle which acts as a nucleus. The droplets gradually sink to the water in the bulb and each one carries a solid particle to the water. Thus many repetitions of the experiment clear the air of solid particles and no more clouds can be formed unless some smoke (or dust) is added to the air in the flask. Thus we verify the fact that solid particles in the atmosphere are necessary to cloud formation. Sometimes it takes many repetitions of the experiment to remove all the solid particles of the smoke. The instructor may wish to save time by first clearing the air and then showing that no clouds can be produced until solid particles have been supplied.

* See footnote on page 9.

Exercises

1. Which would take more gasoline, a flight from California to New York or a return trip? Why?

2. The trade winds are stronger and more constant than the prevailing westerlies. Why didn't the early trans-Atlantic fliers believe that an east-to-west trip in the regions of the trade winds would be safer than a trip from America to Europe?

3. Would you expect a world weather map at any given day to be like figure 2? Explain.

4. How do you explain the fact that Lower California (23°N. lat. to 32°N. lat.) has a very dry climate during all seasons even though it is almost surrounded by water?

5. How much change in pressure and how much change in temperature are represented by the smallest divisions on the horizontal scales of Fig. 1?

6. From Fig. 1, what temperature and what atmospheric pressure would you expect at the top of Mt. Everest? At the greatest height attained by the "Explorer II," which was sponsored by the National Geographic Society?

7. Can you guess why the "horse latitudes" were so named by early explorers?

8. If an observer notices a west wind, in what direction from his position should he expect a low? Make a sketch to illustrate your answer.

9. How much does the atmosphere of a cube 30 by 30 by 30 feet weigh? How many slugs of air are there in this cube? (One slug = 32.2 pounds.)

10. Much of the preface to this book was written to help you. Study it and then answer the following questions:

(a) What suggestions in addition to those given would you make to a student who is beginning the study of physics?

(b) Name five pieces of equipment which a student should bring to each class.

(c) What use can a student make of illustrations in which problems are solved?

CHAPTER 2

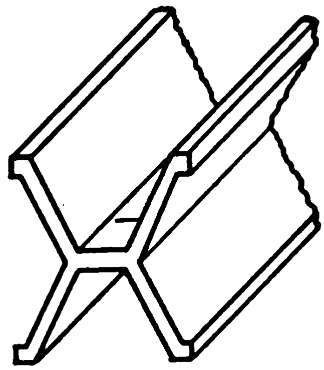
Units of Measure

All physical measurements may be expressed in terms of one or more of the fundamental magnitudes: length, mass, and time. The metric system has been planned very carefully to reduce the amount of arithmetic needed in measurement and to make it easy for the average person to know the entire system of measurement.

Before the middle of the nineteenth century, there was very little uniformity in standards of measurement. Often the length of the king's foot was taken as the standard of length. Whenever a new king was crowned, the standard changed. One can easily realize the confusion that would result if this practice were followed at present. Different countries had different systems of measurement, and differences often existed within a single country. With improved transportation facilities, exchange of goods and ideas grew rapidly and made it necessary for the various nations to choose permanent units of measure and to reduce the number of systems in use. At present, in the United States, two systems of measurement are used: the metric system and the English system. In scientific work, the metric system is used throughout the world. In trade, it is used in practically all countries except Great Britain and the United States.

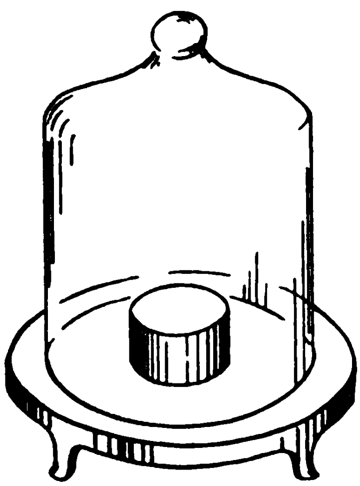
The **meter,** the **kilogram,** and the **second** are the world standard units of measurement. Our yard is legally defined

as $\frac{3600}{3937}$ of a meter. Our pound is defined in terms of the kilogram.



The Standard Meter

The standard **meter** is the distance between two scratches on a platinum-iridium bar at the temperature of melting ice. The standard meter is kept at the International Bureau of Weights and Measures near Paris. Several copies of this standard are kept at the U. S. Bureau of Standards, Washington, D. C.



The Standard Kilogram

The **kilogram** is the mass of a platinum-iridium cylinder which is kept at the International Bureau of Weights and Measures. It is practically equal to the mass of 1,000 cubic centimeters of water at the temperature of its maximum density (about 4°C).

The **second** is $\frac{1}{60}$ of $\frac{1}{60}$ of $\frac{1}{24}$ of a mean solar day. This unit is common to the metric and the English systems of units.

Units of Length

Metric

1 centimeter (cm)	=	10 millimeters (mm).
1 meter (m)	=	100 cm.
1 kilometer (km)	=	1,000 m.

English

1 foot (ft.)	=	12 inches (in.).
1 yard (yd.)	=	3 ft.
1 mile (mi.)	=	5,280 ft.

A **nautical mile** is $\frac{1}{60}$ of a degree of a great circle of the earth. A nautical mile equals 6,080 ft. A **knot is one nautical mile per hour.**

Equivalents:

1 inch = 2.54 cm.
1 meter = 39.37 inches.
1 kilometer = 0.614 miles (or nearly $\frac{5}{8}$ mile).

Units of Mass or Weight

1 gram (g) = 1,000 milligrams (mg).
1 kilogram (kg) = 1,000 g.
16 ounces (oz.) = 1 pound (lb.).
2,000 pounds = 1 ton.
2,240 pounds = 1 long ton or shipping ton.

Equivalents:

1 kilogram = 2.2 pounds.
1 cubic centimeter (cm^3) of water weighs 1 gram.
1 cubic foot ($ft.^3$) of water weighs 62.5 pounds.

Derived Units

Area = length × length. It may be measured in square feet ($ft.^2$), square meters (m^2), etc. 1 square mile = 640 acres.

Volume = length × length × length. It may be measured in cubic feet, cubic centimeters, etc. 231 $in.^3$ = 1 gallon. 1 liter = 1,000 cm^3 = 1.06 quarts.

Density = mass per unit of volume. It is expressed as g/cm^3, $lb./ft.^3$, etc. Density = mass ÷ volume.

TABLE OF DENSITIES

Substance	Grams per cm^3	Pounds per $ft.^3$
Platinum	21.5	
Iron	7.1 to 7.9	444. to 494.
Aluminum	2.7	169.
Woods	0.4 to 1.1	25. to 68.8
Sea water	1.03	64.4
Water	1.	62.5
Gasoline	.68 to .72	43.8 to 46.4
Mercury	13.6	850.
Air (at 0°C, 760 mm)	.00129	.082
Air (at 59°F, 29.92 in.)		.0765

Other derived units. **Speed** and **velocity** involve units of *length* and units of *time*. They may be expressed in miles per hour, feet per second, or any units of length divided by any units of time. The distinction between speed and velocity will be made later on.

The processes of multiplication and division may be carried out with units in the same way that these operations are ordinarily performed with numbers. Thus additional units may be produced: feet × pounds = foot-pounds (units of **work**); kilowatts × hours = kilowatt-hours (units of **energy**).

Units of **power** involve all three of the fundamental units. Power may be measured in foot-pounds per second; thus power is (pounds × feet)/seconds.

The **ohm,** the **ampere,** the **volt,** and all other electrical units are likewise derived from length, mass, and time.

Illustrations

1. A car travels at a speed of 40 miles/hour. How far will it go in 2.5 hours?

$$\begin{aligned}\text{Distance} &= \text{speed} \times \text{time} \\ &= \left(\frac{\text{miles}}{\cancel{\text{hours}}} = 40\right) \times 2.5\ \cancel{\text{hours}} \\ &= 100 \text{ miles.}\end{aligned}$$

2. The specific gravity of a substance is the weight of the substance divided by the weight of an equal volume of water. If two cubic feet of a substance weighs 1,000 pounds, what is the specific gravity of the substance?

$\text{Sp. gr.} = \dfrac{1{,}000\ \cancel{\text{lbs.}}}{2 \times 62.5\ \cancel{\text{lbs.}}} = 8$, an abstract number. Here you see that the units have been cancelled just as numbers of arithmetic are cancelled.

3. Often it is necessary to convert from one set of units to a different set. Years ago, a famous auto racer insisted that some day he would attain a speed of 60 miles per hour, or, as he put it, "a mile a minute." How far would he go each second?

$$
\begin{aligned}
60 \text{ miles per hour} &= 60 \times 5{,}280 \text{ ft./hr.} \\
&= \frac{\cancel{60} \times 5{,}280}{\cancel{60}} \text{ ft./min.} \\
&= \frac{5{,}280}{60} \text{ ft./sec.} \\
&= 88 \text{ ft./sec.}
\end{aligned}
$$

This result should be memorized so that it may be used to convert any number of mi./hr. to ft./sec. Thus 90 mi./hr. = $\frac{90}{60} \times 88$ ft./sec. = 132 ft./sec.

Exercises

1. 231 in.^{3} = 1 gallon (U.S.). How many gallons are there in a cubic foot?

2. 1 kg = 2.2 lb. How many grams are there in a pound?

3. How many centimeters are there in 1 foot?

4. 1 kilowatt (1,000 watts) = 1.3 horsepower. What is the horsepower of a 550-watt electric iron?

5. A man runs 100 yards in 10 seconds. What is his speed in miles per hour?

6. Convert 50 miles to kilometers. Convert 40 km to miles.

7. Recently a man returned to the United States after having been in business in Mexico for many years. His car, having been purchased in Mexico, had a speedometer which indicated km/hr. How high may he allow his speedometer to read when he is in a district in which the speed limit is 30 mi./hr.? How fast (mi./hr.) was he going when his speedometer indicator pointed to 40? In Mexico, this man found that his gasoline tank could hold 40 liters. How many U.S. gallons can it hold?

8. How many square centimeters are there in a square inch?

9. One nautical mile is $\frac{1}{60}$ of a degree of a great circle of the earth. What is the circumference of the earth in nautical miles?

10. A ship has a speed of 10 knots. Express this speed in feet per second.

11. What is the easiest way to find the weight of a cubic foot of a substance if the specific gravity is known?

12. A block of iron measures 10 cm $\times$ 20 cm $\times$ 5 cm. It weighs 7,600 g. What is its density in g/cm^3? In lb./ft.^{3}

13. The specific gravity of a substance is numerically equal to its density expressed in grams per cubic centimeter. Why is this true? Write the specific gravity of each substance listed in our table of densities on page 14.

14. How much does an aluminum block weigh if it measures 4.2 cm $\times$ 5 cm $\times$ 10 cm?

15. Use the result of illustration 3 (page 15) to convert 40 mi./hr. to ft./sec.; 70 mi./hr. to ft./sec.; 120 mi./hr. to ft./sec.; 30 ft./sec. to mi./hr.; and 100 ft./sec. to mi./hr.

16. Gasoline weighs 6 lb./gal. and engine oil weighs 7.5 lb./gal. Express these densities in lb./ft.^{3}

17. In the study of aerodynamics, the density of air is taken as .002378 slugs/ft.^{3} at 59°F and at a pressure of 29.92 inches of mercury. Express this density in lb./ft.^{3} and in g/cm^3. (One slug = 32.2 lb.)

18. A recent advertisement indicates that injection carburetors pass 5 tons of air per hour into each motor of a Flying Fortress. If the density of air is .0765 lb./ft.^{3} how many cubic feet of air does each motor take in one hour?

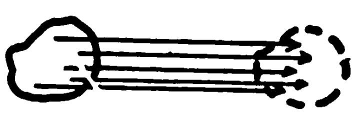
CHAPTER 3

Vectors and Balanced Forces

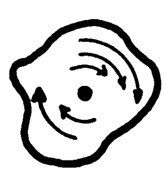
Force is that which causes, or tends to cause, motion or change of motion.

We are held to the surface of the earth by the force of attraction which the earth exerts upon us. When a book rests upon a table, the earth exerts a downward pull upon the book, but no motion is produced, because the table exerts an upward force of equal magnitude upon the book. As far as motion is concerned, these two forces of equal magnitude but opposite directions produce the same effect as no force at all. How would you arrange things so that the book would be acted upon by the downward force only? Would the force cause motion?

The two kinds of motion are **translation** and **rotation.** Some motions are combinations of rotation and translation. In a satisfactory forward pass, the football rotates while it is being "translated" from the passer to the receiver.



Translation



Rotation

To describe a force adequately, one must give its **magnitude** and its **direction.**

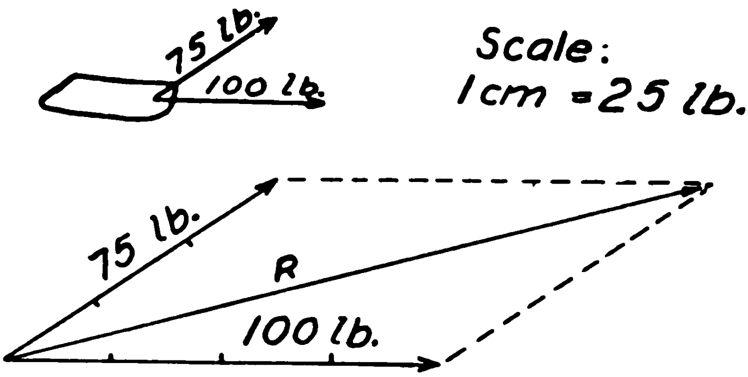
A quantity which has magnitude and direction is called a **vector** quantity. Vector quantities are represented by vectors. A **vector** is a straight line in a given direction with an arrow on one end to indicate the direction in which the vector quantity acts. The length of the vector is laid off to scale to show the magnitude of the vector quantity.

Force, velocity, and **acceleration** are vector quantities.

Quantities like **volume, mass, and heat,** which involve no idea of direction, are called **scalar** quantities.

Addition (or Composition) of Concurrent Forces

Parallelogram of forces. What single force will produce the same effect as is produced by the two forces shown? The answer to this question is obtained by means of the following steps:

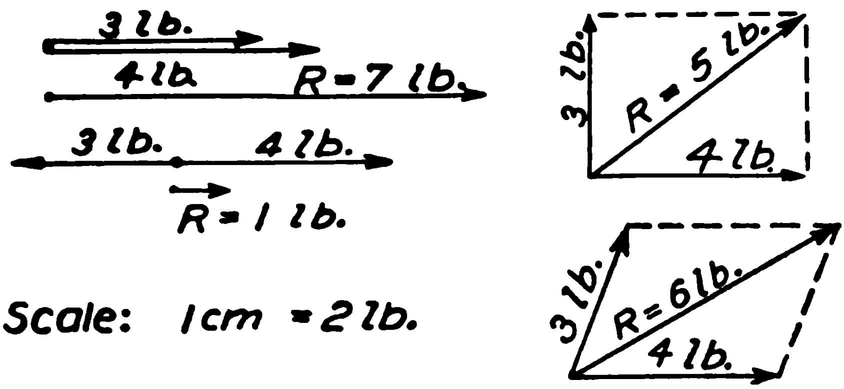


1. The angle between the given forces is reproduced in a second figure.
2. Each force is laid off to scale.
3. The parallelogram is completed.

The diagonal of the parallelogram represents the vector sum of the two original forces. In this instance, the diagonal is found to be 6.8 cm long. Since each centimeter represents 25 lb., 6.8 cm represents 170 lb. This force is called the resultant of the two given forces.

The **resultant** of two or more forces is the single force which will produce the same effect as is produced by the combined action of all of the original forces. It is the vector sum of the original forces. Any set of forces may be replaced by its resultant. The anti-resultant (or **equilibrant**) of a group of forces is the single force that would exactly balance the group of forces. The resultant and the equilibrant are equal in magnitude but are oppositely directed. When the vector sum of all forces acting on an object is zero, the forces are said to be balanced, or in equilibrium. Balanced forces produce no change of motion.

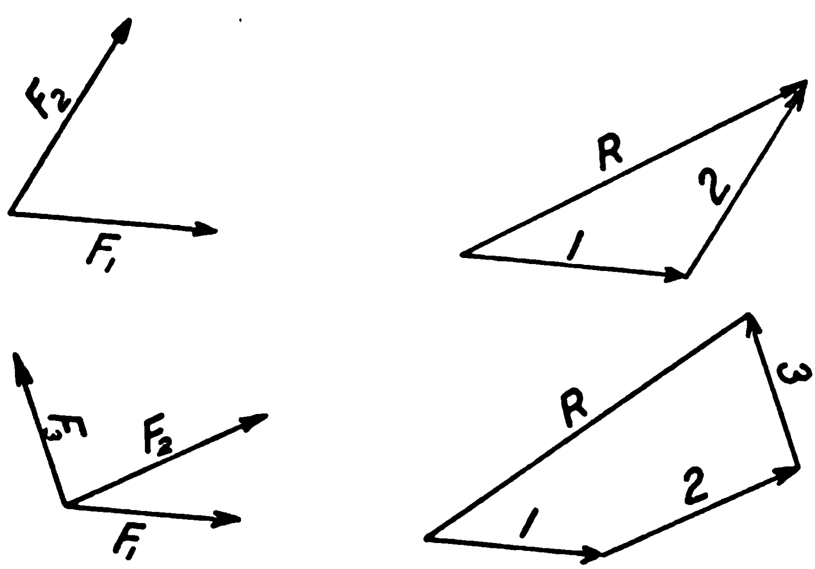
The resultant of two given forces depends upon the angle between the two forces. To illustrate this, let us find the resultant of a force of 3 lb. and a force of 4 lb. for various directions of the two forces.



Thus, when 3 and 4 are added together as vectors, the sum, or resultant, may be anything from 1 to 7.

The polygon method. The polygon method is an abbreviation of the parallelogram method. All lines not actually needed are omitted. The illustrations below show the method.

Find the resultant: *Solution:*

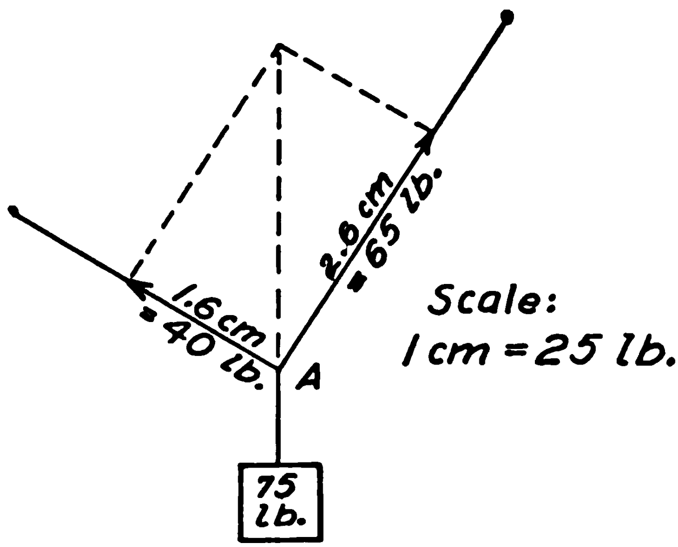


If a system of concurrent forces yields a **closed polygon,** the resultant is 0. That is, the forces are in equilibrium.

If a group of forces is balanced, equilibrium is destroyed when any one of the forces is removed. Thus **every one of a set of balanced forces is the equilibrant of all the others.** This fact must be considered in the solution of many problems.

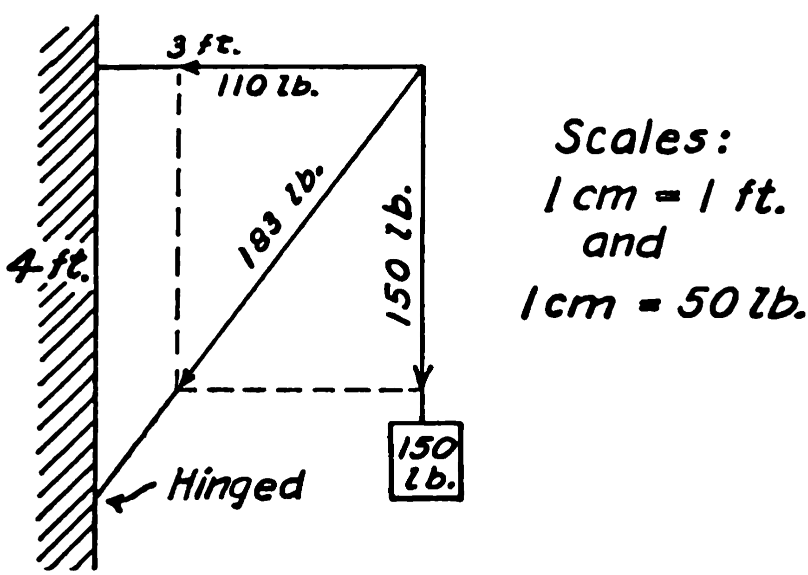
Illustrations

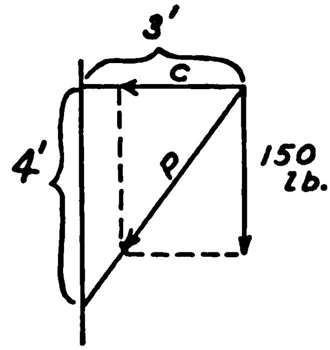
1. Find the tension in each of the inclined cords. The downward force of 75 lb. is the equilibrant of the two inclined forces acting at A. Therefore, the resultant of the two unknown forces is 75 lb. upward. By the construction shown, the tensions are found to be about 65 lb. and 40 lb., respectively. A larger figure would enable us to get more accurate results.



2. Neglecting the weight of the inclined rod, find the force of compression exerted on the rod and the tension in the horizontal cord.

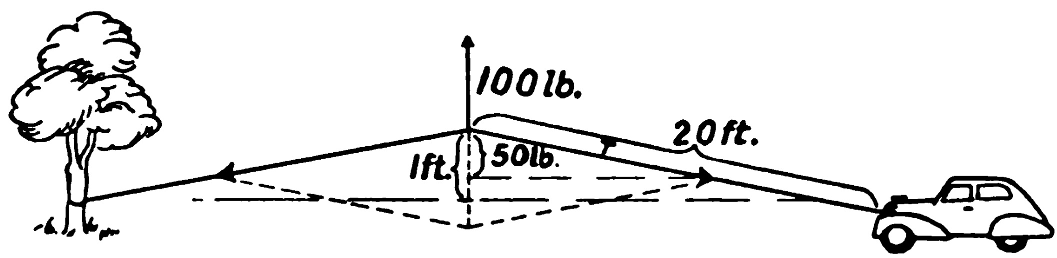
Answer: 183 lb. and 110 lb.





In solving this problem by proportions, a rough sketch is sufficient. In the figure, each of the two force triangles is similar to the 3,4,5 triangle. Therefore $\frac{P}{150} = \frac{5}{4}$ or $P = 187.5$ lb., and $\frac{C}{150} = \frac{3}{4}$ or $C = 112.5$ lb.

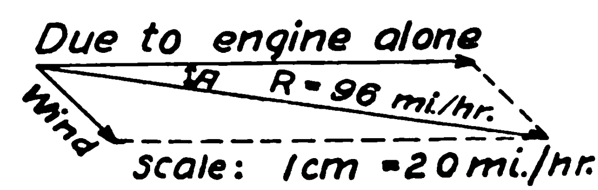
3. At the midpoint of a taut rope, a man exerts an upward force of 100 lb. as indicated. How much force does the rope exert upon the car?



The force acting upon the car is equal to the tension (T) in the rope. To find its magnitude, we consider the three balanced forces at the midpoint of the rope. The resultant of the two inclined forces is 100 lb. downward and the vertical component of each of the inclined forces is equal to 50 lb. Thus

$$\frac{50}{T} = \frac{1}{20} \qquad \text{and} \qquad T = 1{,}000 \text{ lb.}$$

4. The methods given above can be applied to any vector quantities. An airplane that travels 80 mi./hr. when there is no wind is headed due east. There is a northwest wind of 20 mi./hr. Find the magnitude and the direction of the actual velocity of the plane. From the figure, we find that the velocity is 96 mi./hr. and is directed $48\frac{1}{2}°$ south of east.

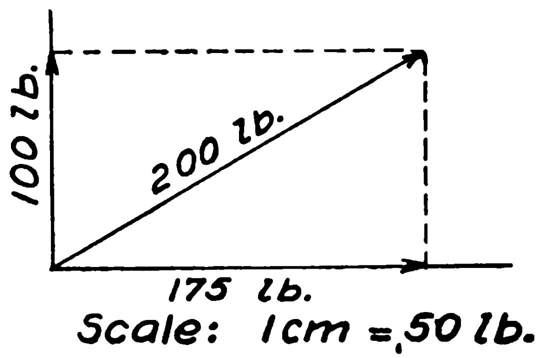


By means of a small device called a "computer," a pilot can add vectors very quickly and without drawing a figure. From the magnitude and direction of the wind and his own air speed, he finds his ground speed and his direction of travel

(his true course). By a bit of maneuvering, the pilot takes observations from which he can find the direction and speed of the wind.

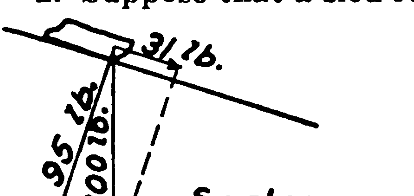
Resolution of Forces

Since two or more forces can be replaced by a single force, it follows that a single force can be replaced by two forces (called components) whose resultant is equal to the single force. The process of resolving a force into components is the reverse of composition. Resolution may be carried out graphically as illustrated. The 200-lb. force may be replaced by a horizontal force of 175 lb. and a vertical force of 100 lb.

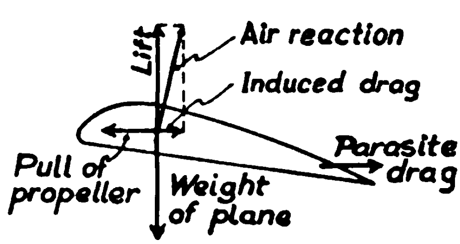


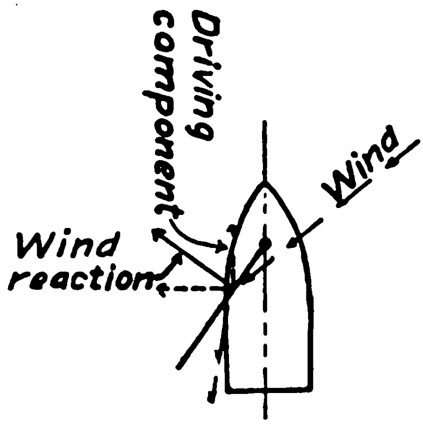
Illustrations

1. Suppose that a sled rests upon a hill as shown. If the sled and its load weigh 100 lb., how much force tends to push the sled down the hill, and with what force does the sled push against the hill? The weight of the sled may be resolved into two components as shown. The component parallel to the hill is 31 lb. and the component perpendicular to the hill is 95 lb.



2. When an airplane is traveling at constant velocity, all forces are balanced. The air reaction is resolved into two components as shown. The vertical component neutralizes the weight of the plane. The horizontal component and the parasite drag are balanced by the pull exerted by the propeller.



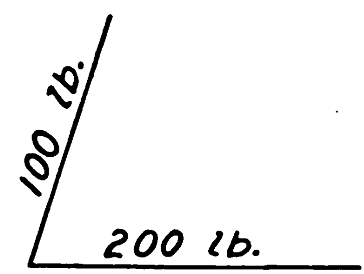


3. Sailing into the wind. (See the figure at the left.)

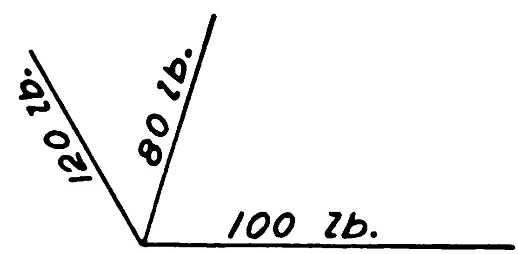
Exercises

1. If you are exerting a force upon a raft, in what way can you change the point of application of the force without changing the effect of the force?

2. Find the resultant in each case below. For the figure at the right, use the polygon method.

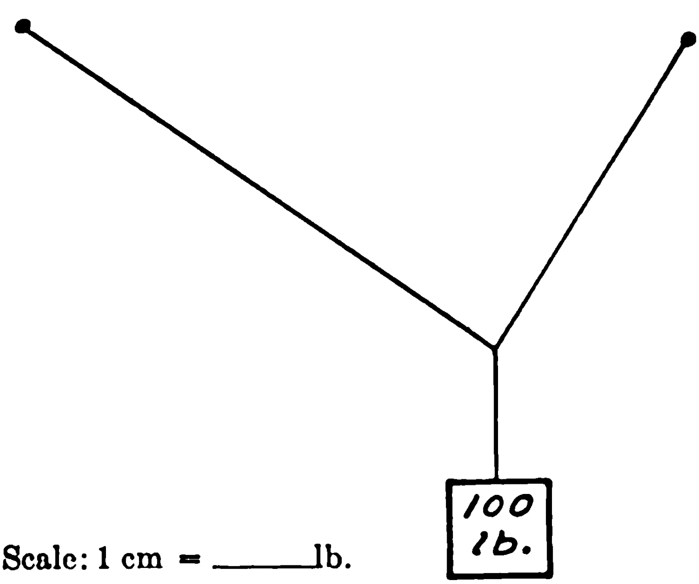


Scale: 1 cm = ______lb.



Scale: 1 cm = ______lb.

3. In the figure below find the tension in each of the inclined cords.



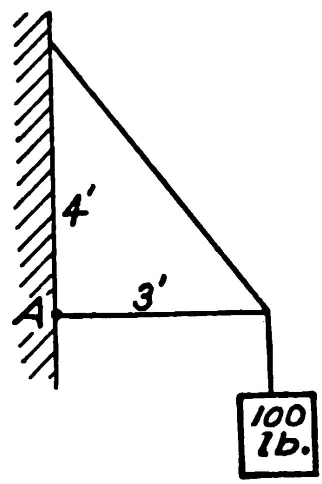
Scale: 1 cm = ______lb.

4. Graphically, resolve each of these forces into a horizontal component and a vertical component: (a) 200 lb. at an angle

of 30° with the horizontal. (b) 500 lb. at an angle of −50° with the horizontal.

5. A 100-lb. object rests upon a 13-ft. plank. One end of the plank is raised 5 ft. above the level of the other end. Resolve the weight of the object into a component parallel to the plank and a component perpendicular to the plank.

6. The horizontal rod is hinged at *A*. Neglecting the weight of the rod, find the tension in the inclined cord and the compression in the rod. The figure is drawn to scale.

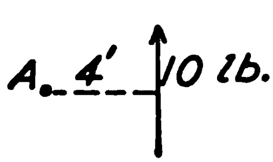


7. A scout radios to his base that, after flying 100 miles east from his base and then 50 miles N.E., he has located a target. In what direction from the base and how far must bombers fly to reach the target? (Solve graphically.)

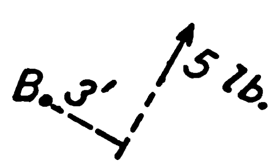
8. On a certain airfoil, the total air reaction makes an angle of 10° with the vertical, and the induced drag is 200 lb. Find the lift and the magnitude of the total air reaction.

Moments of Force

The **moment** of a force measures its tendency to produce rotation. The moment of a force, or torque, about a given axis, is equal to the product of the force times the perpendicular distance from the axis to the force.



Torque about *A* = 40 pound-feet.



Torque about *B* = 15 pound-feet.

Parallel Forces

For the sake of brevity, we shall consider vertical forces only. This will not in any way limit the applications that can be made of the facts to be presented.

Since there are two types of motion—translation and rotation—it follows that there are **two** conditions which must be satisfied by the forces acting upon any object if the forces are to be in **equilibrium.**

For vertical forces, the two **conditions of equilibrium** are:

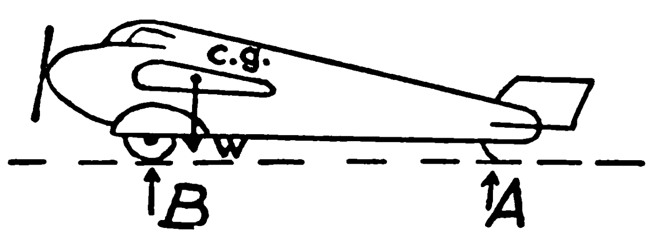
1. The sum of the forces pulling up must be equal to the sum of the forces pulling down. (Then the forces will produce no translation.)
2. The sum of the clockwise moments **about any point** must equal the sum of the counterclockwise moments about the same point. (Then the forces will produce no rotation.)

These conditions of equilibrium form the basis for the solution of any problem involving parallel forces.

The **center of gravity** of an object is the point at which the resultant of the weights of all the particles of the object acts. In all of the problems in this book, we may consider that the entire weight of any object acts at the center of gravity of the object.

Illustrations

1. When a certain 2,200-lb. plane is grounded, its tail skid is 20 ft. (horizontally) behind the front wheels and the center of gravity of the plane is 1.5 ft. behind the wheels. How much load is supported (A) by the skid and (B) by the wheels?



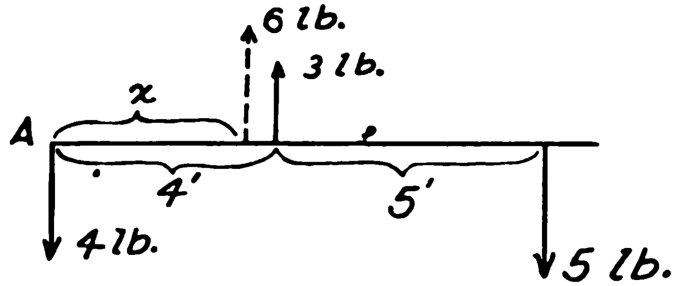
As an axis, consider the line which joins the two points at which the wheels touch the ground. Then:

$$\begin{aligned} \text{Clockwise moments} &= \text{counterclockwise moments} \\ 2{,}200 \times 1.5 &= A \times 20 \\ A &= 165 \text{ lb.} \\ \text{and } B &= 2{,}200 - 165 = 2{,}035 \text{ lb.} \end{aligned}$$

2. If a 180-lb. mechanic climbs onto the plane of illustration 1 at a point which is 8 ft. behind the wheels, how much does the load on the tail skid become?

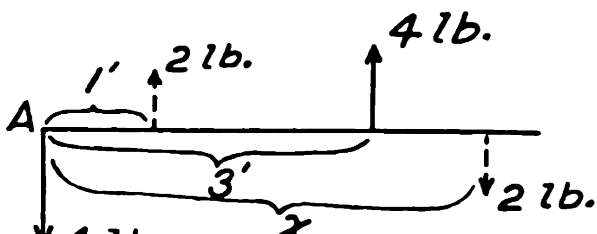
$$2{,}200 \times 1.5 + 180 \times 8 = A \times 20$$
$$A = 237 \text{ lb.}$$

3. Find the equilibrant of the forces shown. Condition 1 tells us that we must add a force of 6 lb. upward to produce equilibrium. Condition 2 enables us to find **where** this force must be applied. Taking moments about A, clockwise moments = counterclockwise moments.



$$5 \times 9 = 6x + 3 \times 4. \qquad x = 5\tfrac{1}{2} \text{ ft.}$$

4. Find the equilibrant of the pair of forces shown. A pair of forces of equal magnitude but opposite directions is called a **couple.** A couple produces a twisting effect but does not produce translation. If we neutralize the twisting effect by adding a single force, the first condition of equilibrium will no longer be satisfied. **A couple can be balanced only by another couple.** To find a couple which will produce equilibrium, we may put any force at any place and find where its mate must be placed. Let us add an upward force of 2 lb. as indicated. Then we must add also a downward force at some distance, x, to the right of A. For equilibrium,



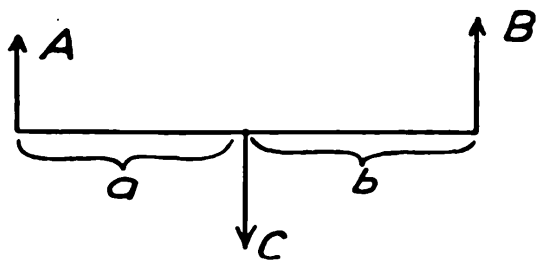
$$\left.\begin{matrix}\text{Clockwise moment}\\ \text{about } A\end{matrix}\right\} = \left\{\begin{matrix}\text{counterclockwise}\\ \text{moments about } A\end{matrix}\right.$$
$$2x = 4 \times 3 + 2 \times 1$$
$$x = 7 \text{ ft.}$$

Check: Moment of original couple $= 4 \times 3 = 12$ (counterclockwise). Moment of neutralizing couple $= 2 \times 6 = 12$ (clockwise).

Exercises

1. A 160-lb. man sits on a balanced plank at a distance of 3 feet from the center of the plank. Where must a 70-lb. boy sit in order to balance the man? Draw a diagram.

2. Find the force or forces which are needed to produce equilibrium in each of the four cases below. Draw a figure for each case.



	A	*B*	*C*	*a*	*b*
(1)........	10 lb.	20 lb.	5 lb.	2 ft.	3 ft.
(2)........	20 kg	10 kg	5 kg	20 cm	10 cm
(3)........	0	10 lb.	20 lb.	—	4 ft.
(4)........	0	10 kg	10 kg	—	30 cm

3. A 30-ft. bridge weighs 10 tons. A 3,000-lb. automobile is on the bridge, 10 ft. from one end. Find the upward forces exerted by the supports which are at the ends of the bridge.

4. Tell where the center of gravity of each of the following objects is located: (a) a rectangular block, (b) a sphere, (c) a doughnut, (d) a hammer. What has been gained by lowering the center of gravity of the automobile? How was the lowering of the center of gravity accomplished? What would happen to the center of gravity of an automobile and its load if all of the passengers were to sit (a) upon the roof of the car, (b) in the rear seat?

5. Tell all you can as to how the distribution of the load of a plane affects the location of the center of gravity of the plane and its load.

6. If a plane noses over when the landing brakes are applied, where is the axis about which the plane turns? Make a diagram to show how far a plane can tilt before it noses over. Explain.

7. Solve exercise 34 on page 107 if the given distances are changed from 3 ft. and 4 ft. to 5 ft. and 12 ft., respectively.

8. Solve exercise 33 on page 107 if the distances given are changed from 4 ft. and 6 ft. to 3 ft. and 5 ft., respectively.

9. State the two conditions of equilibrium for parallel forces. Why are there two? Of what value are they?

10. Define the **moment** of a force. If a body is in equilibrium, prove that the clockwise moments about **any** axis must equal the counterclockwise moments about the same axis. Hint: What would happen if this condition were not satisfied?

11. Find the loads supported by the skid and the wheels in illustrations 1 and 2 if the center of gravity of the plane is 1 ft. behind the wheels and the mechanic's weight is 140 lb.

12. In an emergency, a pilot strapped a 160-lb. load to the wing of his plane. If this extra load was 4 ft. from the center of the plane, how much torque did the ailerons have to exert to keep the plane in level flight? If the load was to the pilot's left, was the aileron torque clockwise or counterclockwise?

A fundamental principle of mechanics tells us that any motion which an airplane can have consists of a motion of its center of gravity plus a rotation about an axis through the center of gravity. For a plane which is in level flight, the rotation about the center of gravity is 0. Then moments about any line drawn through the center of gravity must be perfectly balanced.

13. If the lift, thrust, and drag exert a total moment of 2,000 lb.-ft., tending to make the plane nose up, and if the force on the tail is vertical and acts at a point 12 ft. from the center of gravity of the plane, how much tail force is needed to keep the plane in level flight? In this instance, is the required force on the tail up or down?

14. An extra load of 4,000 lb. is placed 4 ft. behind the center of gravity of a transport plane. How much additional upward force must be exerted on the tail surface to keep the plane in level flight if the tail surface is 45 ft. behind the center of gravity of the plane?

CHAPTER 4

Accelerated Motion and Laws of Motion

Speed implies magnitude only, while **velocity is a vector quantity.** If a motorist keeps his speedometer at 20 miles/hr. while traveling round a lake, his speed is constant but his velocity is not.

Acceleration is the **rate of change of velocity.** The change may be change in magnitude, direction, or both.

First we will confine our attention to motion in a straight line, linear motion. Then the distinction between speed and velocity disappears and any acceleration will involve a change in the magnitude of a velocity. The expression $a = 20$ mi./hr./sec. means that, each second, the velocity is increased by 20 miles per hour. The gain per second, 20 mi./hr., is equal to $\frac{20 \times 5{,}280}{60 \times 60}$ ft./sec./sec., or 29.3 ft./sec./sec. If this acceleration is maintained for 3 seconds, the total gain in velocity will be 60 mi./hr.

For constant acceleration:

$$\text{Gain in velocity} = \text{acceleration} \times \text{time}.$$

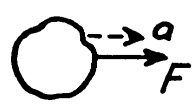
It is common knowledge that for great acceleration or "pick-up" an automobile should have a powerful engine and a small total weight.

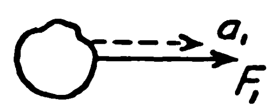
Newton's **three laws of motion** form the basis for more exact study of velocity, acceleration, force, and other related topics. The laws may be stated as follows.

1. Every object persists in a state of rest or of uniform motion in a straight line unless acted upon by some **unbalanced force.**
2. The **acceleration** of an object is **proportional to the unbalanced force** acting upon it and is in the direction of the force
3. For every action (or force) there is an equal and opposite **reaction.** (Action and reaction never act on the same object.)

Imagine that, on a certain object, the unbalanced force is first F and then F_1. Newton's second law tells us that the acceleration will satisfy the proportion,

(1) $$\frac{a}{a_1} = \frac{F}{F_1}.$$





If an object is allowed to drop, the unbalanced force acting on it is the weight, w, of the object. The acceleration is found by experiment to be about 32 ft./sec./sec. or 980 cm/sec./sec. The letter g is used to designate this acceleration. Thus in the proportion (1), we know that the acceleration is g when the force is w, and the proportion becomes:

(2) $$\frac{a}{g} = \frac{F}{w} \qquad \text{or} \qquad F = \frac{w}{g}\,a.$$

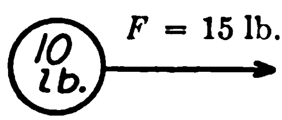
From the second equation, the acceleration of any object can be calculated if the weight of the object and the unbalanced force acting upon it are known. In the English system, $\frac{w}{g}$ is called the **mass in slugs.**

The acceleration caused by gravity varies from place to place. At the equator it is about 977 cm/sec./sec.; at the *poles it is* about 983 cm/sec./sec. Very often the dyne is used as a unit of force. A **dyne** is a force which will give a mass of **1 gram** acceleration of **1 cm/sec./sec.** One of the

chief advantages of the use of the dyne lies in the fact that the value of a dyne is always the same, while the gram of force (pull of gravity upon a mass of one gram) varies slightly with geographical position. With this unit of force, the equation $F = \frac{w}{g} a$ may be written:

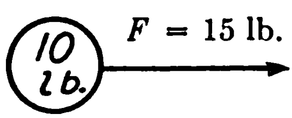
$$F(\text{dynes}) = m(\text{grams}) \times a(\text{cm/sec./sec.}).$$

Illustrations

1. 

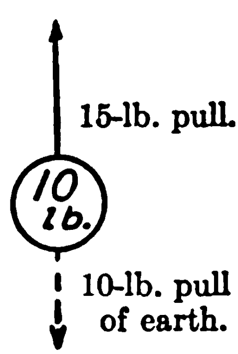
(No friction.)

$F = \frac{w}{g} a$, $15 = \frac{10}{32} a$, $a = 48$ ft./sec./sec.

2. 

(2 lb. friction.)

$F = \frac{w}{g} a$, $13 = \frac{10}{32} a$, $a = 41.6$ ft./sec./sec.

3. 

$F = \frac{w}{g} a$, $F = 15 - 10 = 5$

$5 = \frac{10}{32} a$, $a = 16$ ft./sec./sec.

Equations of motion of an object which moves in a straight line, with a constant acceleration, the acceleration being in the line of motion.

The **velocity** at any **time** (t) is equal to the initial velocity, v_0, plus the gain in velocity, $a \times t$. Thus,

(a) $$v = v_0 + at.$$

The net *distance* traveled is

$$S = (\text{average velocity}) \times (\text{time})$$

$$= \left[\frac{(\text{initial velocity}) + (\text{final velocity})}{2}\right] \times (\text{time})$$

$= \dfrac{v_0 + (v_0 + at)}{2} \times (\text{time})$. Therefore,

(b) $$S = v_0 t + \tfrac{1}{2}at^2.$$

In one of the following lessons we will prove the third relation,

(c) $$v^2 = v_0^2 + 2aS.$$

In these important equations v, a, and S are **vector quantities.** If, in a problem, two of them are oppositely directed, one must be considered **positive** and the other must be taken as **negative.**

If the object starts from rest, the initial velocity is 0 and the equations become:

(a′) $v = at$, (b′) $S = \frac{1}{2}at^2$, and (c′) $v^2 = 2aS$ or $v = \sqrt{2aS}$.

Illustrations

1. A 25-lb. force acts upon a 100-lb. object for 5 seconds. Find the acceleration, the final velocity, and the distance covered in 5 seconds.

$$F = \frac{w}{g}a, \quad 25 = \frac{100}{32}a, \quad a = 8 \text{ ft./sec./sec.}$$

$$v = 8 \times 5 = 40 \text{ ft./sec.,} \quad S = \frac{8 \times 5^2}{2} = 100 \text{ ft.}$$

2. A man dives from a height of 36 ft. With what speed does he hit the water?

$$v = \sqrt{2aS} = \sqrt{2 \times 32 \times 36} = 8 \times 6 = 48 \text{ ft./sec.}$$

3. An object is shot vertically upward with an initial velocity of 144 ft./sec. For how many seconds will it rise?

$$v = v_0 + at.$$

It will rise until its velocity becomes 0. Thus

$$0 = 144 - 32t, \qquad \text{and} \qquad t = 4.5 \text{ seconds.}$$

Minus 32 was substituted for a because we took the upward initial velocity as positive, and the acceleration due to gravity is downward. If the object had been shot downward, the equation would have been $v = 144 + 32t$.

4. Where would the object mentioned in (**3**) be at the end of 4 seconds?

$$S = v_0t + \tfrac{1}{2}at^2, \qquad S = (144 \times 4) - \frac{32 \times 16}{2},$$
$$= 320 \text{ feet (above the earth).}$$

Momentum, Impulse, Impacts

Momentum (amount of motion) = mass × velocity $= \dfrac{w}{g}\,v$.

Impulse = force × time = change of momentum.

If $v_0 = 0$, then $\qquad Ft = \dfrac{w}{g}\,v.$

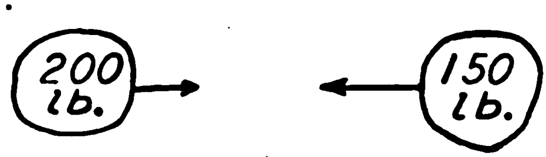
This may be proved as follows:

$$F = \frac{w}{g}\,a, \qquad Ft = \frac{w}{g}\,at = \frac{w}{g}\,v.$$

In a collision, total momentum before impact = total momentum after impact. This is an exact relation which does not depend upon any simplifying assumptions such as the assumption that friction may be disregarded. When this relation is used, velocities in opposite directions must be given opposite algebraic signs.

Illustrations

1. If these two objects stick together after they collide, find their common velocity.

20 ft./sec.  30 ft./sec.

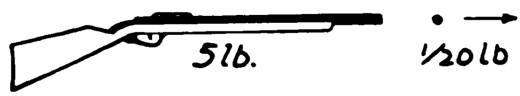
Momentum before collision = momentum after collision.

$$\frac{200}{\cancel{g}} \times 20 - \frac{150}{\cancel{g}} \times 30 = \frac{(200 + 150)}{\cancel{g}} v.$$

$$350v = -500$$

$$v = -1.43 \text{ ft./sec.}$$ What does the minus sign mean?

2. A 5-lb. rifle shoots a .05-lb. bullet with a velocity of 1,000 ft./sec. Find the velocity of recoil of the gun.



Momentum before impact = momentum after impact.

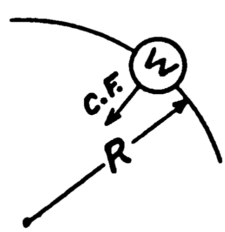
$$0 = .05 \times 1{,}000 - 5v.$$

$$v = 10 \text{ ft./sec.}$$

Curvilinear Motion, Centrifugal Force

When an object moves in a curved path, the direction of its velocity is always changing. Any change of velocity requires a force. In this case, the force is directed toward the center of curvature of the path and is called **centripetal** (toward the center) force. Its magnitude is given by the equation

$$\text{C.F.} = \frac{w}{g} \cdot \frac{v^2}{R}$$



For a plane making loops or turns at constant speed, the centripetal force varies with the sharpness of the turns as indicated. If the speed is increased from 100 mi./hr. to 141 mi./hr., *these forces are doubled.*

Centrifugal means "tending away from the center." In a turn, the force which the seat of the plane exerts upon the

pilot is the centripetal force, and the force which the pilot exerts upon the seat is the centrifugal force. Test pilots are very thoroughly "taped" to protect themselves against these forces. In coming out of a steep dive, the pilot loses consciousness for a short time. Young men regain consciousness much quicker than do older men.

Illustration

A 2,000-lb. car travels 60 mi./hr. (88 ft./sec.) on a 1-mi. circular track. How much centripetal force acts upon the car?

$$\text{C.F.} = \frac{w}{g} \cdot \frac{v^2}{R} = \frac{2{,}000}{32} \times \frac{(88)^2}{5{,}280/2\pi}$$
$$= 576 \text{ lb.}$$

What exerts this central push upon the car?

Trajectories

The path of a bomb, a bullet, or a golf ball is called the trajectory. A high-speed bullet has a relatively "flat" trajectory. If air resistance were not encountered, every trajectory would be a true parabola. After any object is thrown into the air in any direction, it is acted upon by the force of gravity alone and has a downward acceleration of 32 ft./sec./sec. Neglecting air resistance, we find that the path of any projectile is determined by its initial velocity and the force of gravity. If the initial velocity is 0, the object will fall downward 16 ft. during the first second, 64 ft. during the first two seconds, 144 ft. during the first three seconds, and so on.

Now, suppose that an object is shot vertically upward with an initial velocity of 96 ft./sec. If the initial velocity were the only cause of motion, the object would rise 96 ft. in 1 sec. If gravity were the only cause of motion, the object would fall 16 ft. during the first second. Combining the effect of the

initial velocity with the effect due to gravity, we find that, in 1 second,

$$S = 96 \text{ ft.} - 16 \text{ ft.} = 80 \text{ ft.}$$

In two seconds,

$$S = (2 \times 96) - 64 = 128 \text{ ft.}$$

The complete excursion may be charted as follows:

Time (sec.)	1. Rise due to initial velocity $= 96t$	2. Fall due to gravity $= 16t^2$	Net rise, $S = (1) - (2)$
0	0	0	0
1	$96 \times 1 = 96$ ft.	16 ft.	80 ft.
2	$96 \times 2 = 192$ ft.	64 ft.	128 ft.
3	$96 \times 3 = 288$ ft.	144 ft.	144 ft.
4	$96 \times 4 = 384$ ft.	256 ft.	128 ft.
5	$96 \times 5 = 480$ ft.	400 ft.	80 ft.
6	$96 \times 6 = 576$ ft.	576 ft.	0 ft.

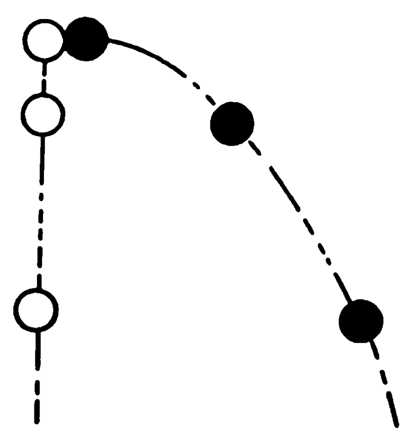
The formula $S = v_0t + \frac{1}{2}at^2$ could be proved in the manner in which the above equations were obtained. The important fact is that gravity will produce a displacement,

$$S = \tfrac{1}{2}at^2,$$

while the initial velocity is producing a displacement,

$$S = v_0t.$$

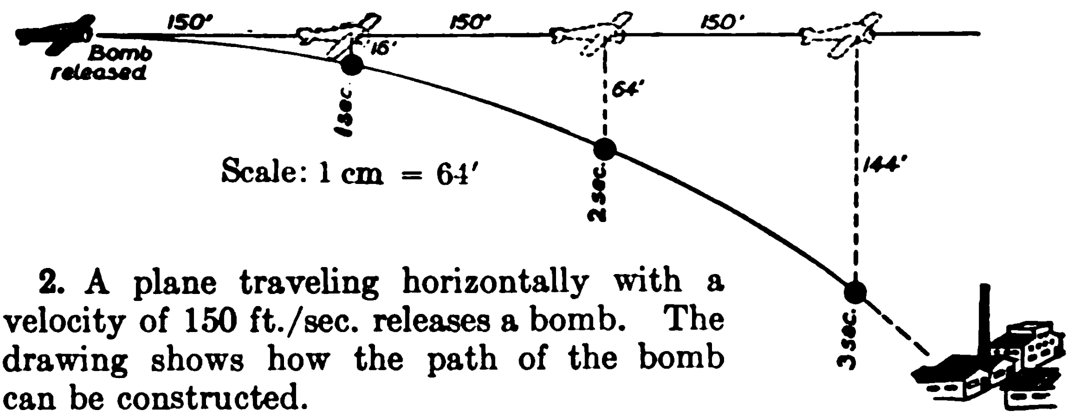
An object which is thrown horizontally falls exactly as far as one which is dropped from rest. Both will strike the floor at the same time. The paths of two such objects are shown by the diagram.



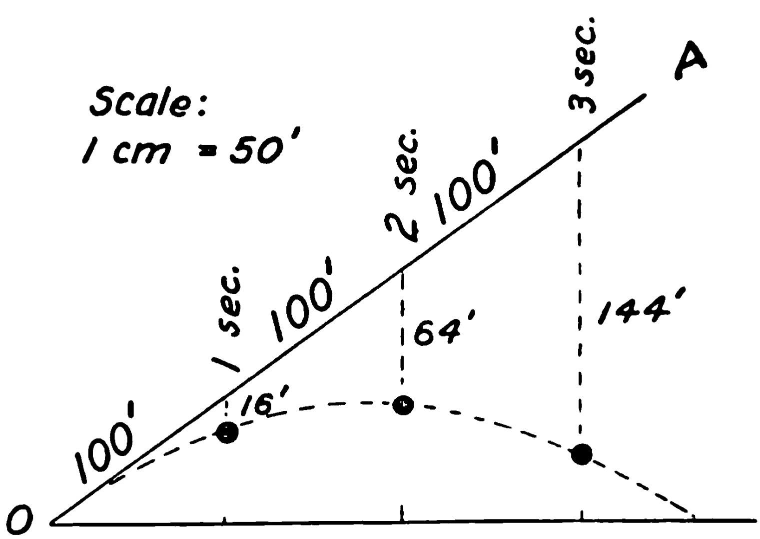
Illustrations

1. From a height of 81 ft., a ball is thrown horizontally with a velocity of 60 ft./sec. How far forward will the ball travel before it strikes the earth? Each second that the ball is in the air, it goes forward 60 ft. The time of flight is obtained from $S = \frac{1}{2}at^2 = 16t^2$. Then $81 = 16t^2$ and $t = \sqrt{\frac{81}{16}} = \frac{9}{4}$ sec., and the horizontal distance covered is

$$60 \times \frac{9}{4} = 135 \text{ ft.}$$



2. A plane traveling horizontally with a velocity of 150 ft./sec. releases a bomb. The drawing shows how the path of the bomb can be constructed.



3. A ball is thrown in the direction OA with a speed of 100 ft./sec. Construct the path. The path is as indicated.

Exercises

Acceleration.

1. A billiard ball traveling at right angles to the cushion of a billiard table at 20 ft./sec. rebounds with a velocity of 18 ft./sec.

along its original path. How much was the change (a) in speed and (b) in velocity? If the ball was in contact with the cushion for .01 sec., what was the average value of its acceleration?

2. An automobile accelerated from 30 mi./hr. to 60 mi./hr. in 4 seconds. Express this acceleration in ft./sec./sec.

3. If the brakes of a car cause a retardation of 11 ft./sec./sec., in how many seconds will they stop the car if the car is going 60 mi./hr.?

4. Solve the equation for acceleration:

$$\text{Change in velocity} = \text{acceleration} \times \text{time}.$$

What "time" is meant here? Express your final equation in words to form a modified statement of the definition of acceleration. This form of the definition of acceleration is preferred by some.

Newton's second law or $F = \dfrac{w}{g}\,a.$

5. How much tractive force must the engine in (**2**) produce if the car weighs 2,000 lb.?

6. A 30-lb. object is fastened to one end of a cord. A 20-lb. object is fastened to the other end. The cord is then hung over a very light, frictionless pulley. How much unbalanced force is there to cause acceleration? How much mass is accelerated? How much acceleration is produced?

7. A 20-lb. object is placed upon a frictionless inclined plane. The plane is 13 ft. long and one of its ends is 5 ft. above the level of the other end. Find the component of force which causes acceleration and find the acceleration produced.

8. In a delayed parachute jump, a man meets an air resistance of $\dfrac{v^2}{75}$ lb. v is the man's velocity, in mi./hr. What is his acceleration when his velocity is 0, 100 mi./hr., 120 mi./hr.? The man and his equipment weigh 192 lb.

9. After the parachute in (**8**) opens, the air resistance becomes $\frac{12}{25}v^2$. With the parachute, at what velocity will the man's acceleration become 0?

Equations of motion.

Most of the problems to which these equations apply can be solved by use of only one of the equations. The equation to use is the one that involves only those quantities which are given in the statement of the problem and those quantities which are to be found.

10. Fill in the blank spaces of the following table for a freely falling body which starts from rest. Use g = 32 ft./sec./sec.

Time of Fall (*sec.*)	*Velocity* (*ft./sec.*)	*Total Distance Fallen* (*ft.*)	*Distance Fallen During the Second* (*ft.*)
0	______	______	______
1	______	______	______
2	______	______	______
3	______	______	______
4	______	______	______
$4\frac{1}{2}$	______	______	______

11. To check his altimeter, a pilot, flying horizontally, drops a stone into the ocean. He sees the splash 5.4 seconds later. What is his altitude?

12. A parachutist hits the ground with the velocity he would get by jumping from a height of 10 ft. Express this velocity in ft./sec. and in mi./hr.

13. In level bombing, how long does it take for a bomb to reach the earth from a height of 10,000 ft.? The time is the same as the time it would take to fall 10,000 ft. vertically downward.

14. What velocity does an object gain in falling from a height of 100 ft.?

15. From what height must an object be dropped so that its final velocity will be 75 ft./sec.?

16. An object is shot vertically upward with an initial velocity of 144 ft./sec. For how many seconds will it continue to rise? What velocity will it have at the end of the first 3 seconds? Where will it be at this time? Does the acceleration of the object change at any point in its flight? What causes the acceleration of the object? Does it change?

Momentum, impulse, impacts.

17. A 30-ton railroad engine, with no train, hits a stalled auto and carries it along. The auto weighs 1 ton. Find the common velocity after impact if the train had been traveling at a rate of 30 mi./hr.

18. A 1,000-lb. gun shoots a 2-lb. bullet with a muzzle velocity of 1,200 ft./sec. Find the velocity of recoil of the gun.

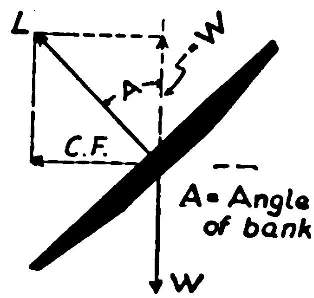
19. If in (**18**) the bullet took .005 sec. to travel the length of the gun, what average force did the explosion exert upon the bullet?

Curvilinear motion.

20. A 10-lb. object travels 20 ft./sec. in a circle whose radius is 3 ft. Find the centripetal force.

21. A pilot can stand 5 "g's" of acceleration. At how small a radius can he take a turn at 120 mi./hr.?

22. When a plane makes a 45° bank at constant altitude, the centripetal force is numerically equal to the weight of the plane. What is the radius of the path of a plane when it makes a 45° bank at 100 mi./hr.? At 120 mi./hr.?



23. For a 45° bank as in (**22**), express the lift, L, which the wings must withstand in terms of the weight, w, of the plane and its load. (See figure.)

24. The ratio $\frac{L}{w}$ is called the load factor. Find, graphically, the load factor for a 30° bank and for an 80° bank. A 90° bank at constant altitude is impossible. Why? Why must a designer consider load factors? In addition to banking, a large load factor may be brought into play in dives, in loops, and by gusts of wind. (A licensed plane must be able to withstand a vertical gust of 30 ft./sec.)

Trajectories.

25. An object is shot at an angle of 45° with the horizon, with an initial velocity of 100 ft./sec. Construct the path for the first 3 seconds.

26. From the top of a high building, a ball is thrown horizontally with a velocity of 50 ft./sec. Construct the path for the first 4 seconds.

27. If the building (exercise 26) is 100 ft. high, how far (horizontally) will the ball travel before it strikes the earth?

28. In level bombing from 20,000 ft., how far forward does the bomb travel if the velocity of the bomber is 120 mi./hr.?

29. An object is projected so that its vertical component of velocity is 96 ft./sec. and its horizontal component of velocity is 50 ft./sec. For how many seconds will it continue to rise? To what maximum height will it rise? How far forward will it go before it strikes the earth?

CHAPTER 5

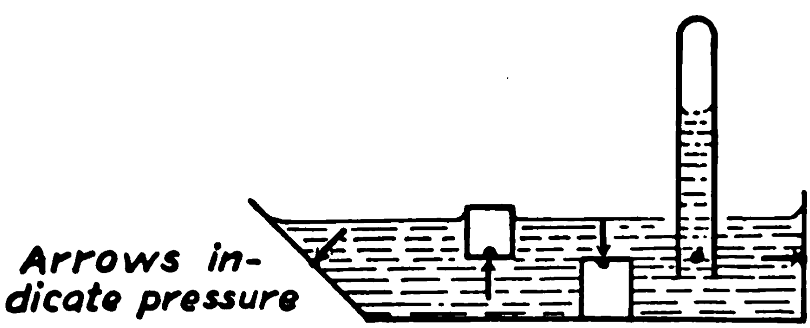
Fluids at Rest

Gases, liquids, and vapors are called **fluids.**

Pressure is force per unit area.

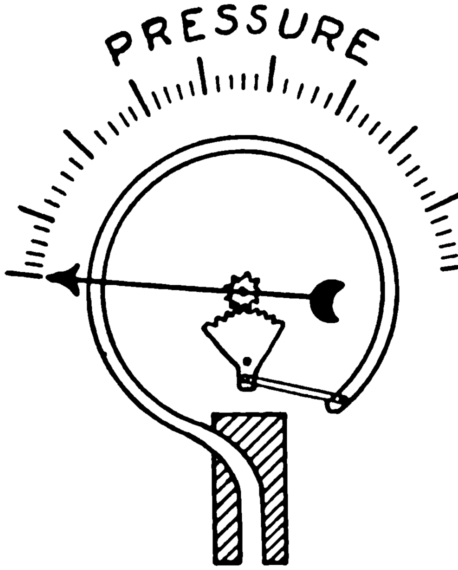
The pressure exerted by a liquid is equal to the weight of a column of the liquid which lies above a horizontal unit of area. Water weighs 62.5 pounds per cubic foot. Therefore, pressure due to water (lb./ft.^{2}) = 62.5 $\times$ depth (feet). In the metric system, the density of water is 1 gram per cubic centimeter. Thus pressure due to water (g/cm^2) = 1 $\times$ depth (cm). In other words, the pressure (in g/cm^2) is numerically equal to the depth (in cm) of the water.

Pressure always acts at right angles to the surface of a container and is exerted equally in all directions. In the figure, the pressure is the same at each point indicated since each point is equally far below the surface.



The force acting upon a surface is equal to **pressure** $\times$ **area.** An automobile oil-pressure gage is shown on the next page.

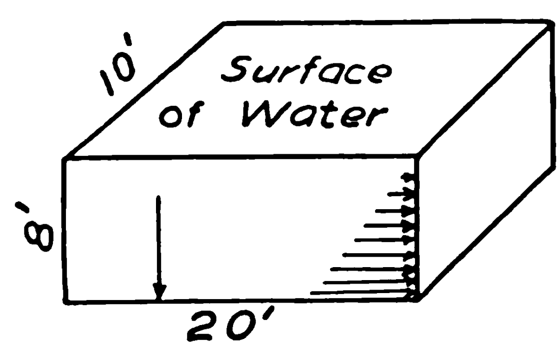
The oil enters the flattened tube and tends to straighten it, just as a garden hose straightens when the water is turned on. This causes the pointer to rotate further as the pressure is increased. The Bourdon gage is the most common type.



Bourdon Gage

In some discussions it becomes necessary to distinguish between "gage pressure" and total or "absolute pressure." If the pressure inside a tank is equal to atmospheric pressure, an ordinary gage attached to the tank would read 0. The amount by which the pressure inside the tank exceeds atmospheric pressure is called the "gage pressure." The actual pressure is called the "absolute pressure." If a student calculates a pressure exerted by the weight of a liquid, his answer is the gage pressure. If he wants the absolute pressure, he must add atmospheric pressure to his answer. Ordinarily, in discussing liquid pressures, we are interested in the gage pressure only.

On a vertical wall, the pressure due to a liquid varies uniformly as indicated by the length of the arrows in the figure. The **average** pressure on the end of the tank of water shown is 62.5 × (average depth); that is, 62.5 × 4 = 250 lb./ft.^{2} The force acting upon the end of the tank is (average pressure) × (area) = 250 × 8 × 10 = 20,000 lb. The force acting upon the bot-



tom of the tank is (62.5 × 8) × (10 × 20) = 100,000 lb. Note that the force acting upon the bottom of the tank is equal to the total weight of the liquid.

Buoyancy; Archimedes' Principle

Archimedes' principle states that (1) an object that is submerged in a fluid is buoyed up by a force that is equal to the weight of its own volume of the fluid and (2) that an object which floats in a fluid displaces its own weight of the fluid—that is, the buoyant force is equal to the weight of the object.

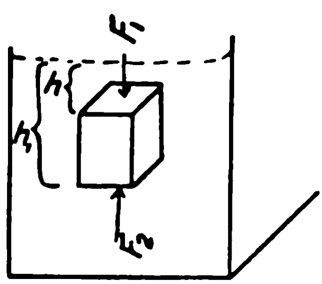


Figure 1

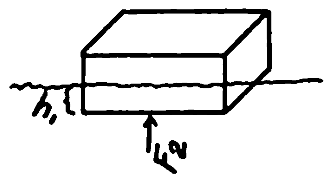


Figure 2

In figure 1 the upward force is $F_2 = h_1da$, where d = density of the liquid and a is the area of the top, or bottom, of the object. The downward force is $F_1 = hda$. The resultant upward force, the buoyant force, is

$$\begin{aligned} h_1da - hda &= (h_1 - h)ad \\ &= (\text{volume of object}) \times (\text{density of liquid}) \\ &= \text{weight of displaced liquid.} \end{aligned}$$

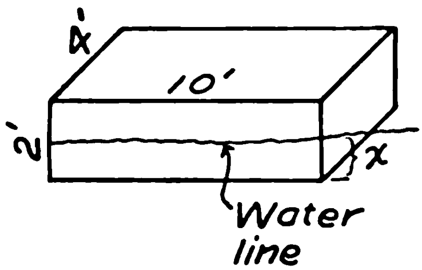
In figure 2 the upward force is

$$\begin{aligned} F_2 &= h_1da = h_1ad \\ &= (\text{volume of displaced liquid}) \times (\text{density of liquid}). \end{aligned}$$

Since the object floats, this upward force must be equal to the weight of the object. The liquid exerts no downward force upon the floating object. Archimedes' principle is often used to find the volume of an irregular object, or to find the specific gravity of a solid or of a liquid.

Illustrations

1. The raft indicated is made of solid wood which weighs 50 lb./ft.³ How far will it sink into fresh water?



Solution:

The raft will sink until it displaces its own weight of water.

Weight of raft = weight of displaced water.

$$50 \times 2 \times \cancel{4} \times \cancel{10} = 62.5 \times x \times \cancel{4} \times \cancel{10}$$

$$x = 1.6 \text{ feet.}$$

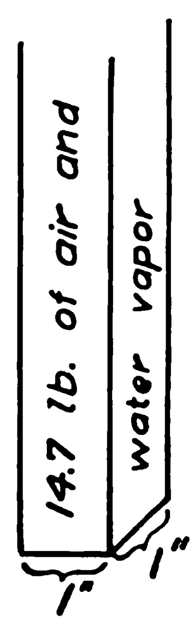
2. An object weighs 10 g in air, 8 g in water, and 8.5 g in alcohol. Find (a) the specific gravity of the object, (b) the specific gravity of the alcohol, and (c) the volume of the object. Solution:

$$\text{(a) Sp. gr. of object} = \frac{\text{weight of object}}{\text{weight of equal volume of water}} = \frac{10}{10-8} = 5.$$

$$\text{(b) Sp. gr. of alcohol} = \frac{\text{weight of displaced alcohol}}{\text{weight of equal vol. of water}} = \frac{10 - 8.5}{2} = 0.75.$$

(c) The object displaces 2 g of water. The volume of 2 g of water is 2 cubic centimeters. Therefore, the volume of the object is 2 cm.³

Atmospheric Pressure

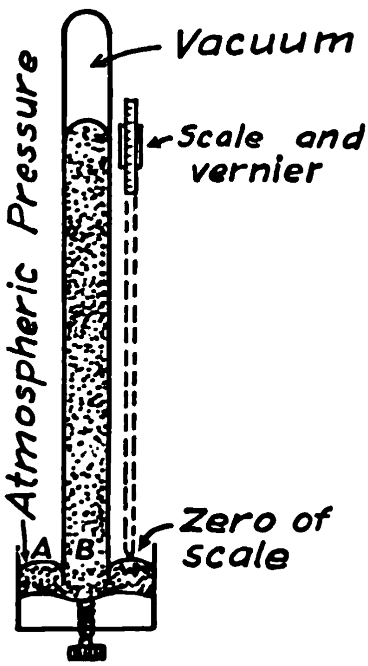


The average value of atmospheric pressure, at sea level, is 14.7 pounds per square inch. This is equal to the pressure that would be exerted by a 34-ft. depth of water or a 76-cm (=29.92-in.) depth of mercury. This pressure is equal to the weight of the atmosphere above a unit of area. Atmospheric pressure decreases with altitude at a rate of about 0.5 lb./in.² for each 1,000 ft. of increase in altitude. (See Fig. 1, page 4.)

Ordinarily we are not conscious of the fact that the atmosphere exerts a considerable pressure. This is because forces due to atmospheric pressure are usually balanced. However, some of us have

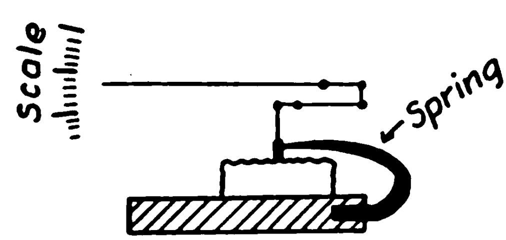
noticed unpleasant effects due to quick changes in atmospheric pressure. The magnitude of atmospheric pressure may be demonstrated by boiling water in an old can for a while, sealing the can, and allowing it to cool; or by pumping the air out of the can.

A **barometer** is a device for measuring atmospheric pressure. There are two types of barometers: the **mercury** barometer and the **aneroid.** The mercury barometer is the standard precision instrument for fixed installation. The pressure at *A* (atmospheric pressure) is equal to the pressure at *B* which, in turn, is equal to the pressure exerted by the column of mercury from *B* upward. Thus atmospheric pressure is measured by the height of the mercury as indicated on the scale. For accurate work, the mercury barometer must be corrected for capillary depression, temperature, and gravity.



Mercury Barometer

The **aneroid** barometer is made of an air-tight box of very thin metal. The box is evacuated so that the upper surface presses upon an external spring which keeps the box from collapsing. If much air were left in the box, variations of the inside pressure due to temperature changes would cause serious errors. As atmospheric pressure increases, the top of the box is pushed downward very slightly. This motion is greatly magnified by a system of levers as indicated in the figure. Aneroid barometers have been improved constantly.

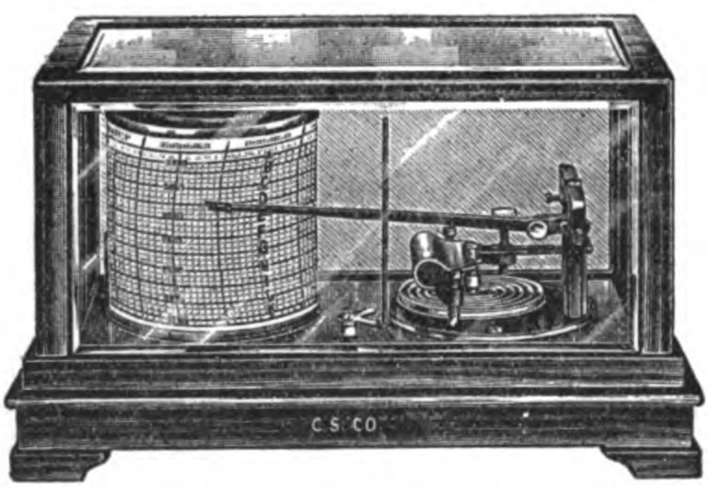


Aneroid Barometer

Today the best ones are almost as reliable as the mercury barometer. In addition to being small and rugged, they can be read quickly and can be made very sensitive. It has been said that the most sensitive aneroid barometers show a change in reading when they are moved from the top of a desk to the floor.

The scale may be laid off to indicate pressure in centimeters or inches of mercury; or the instrument may be used as an altimeter by means of a scale which is marked off in feet of elevation. For the latter use, the instrument is provided with a means of adjusting the zero reading to correspond with the pressure on the earth's surface.

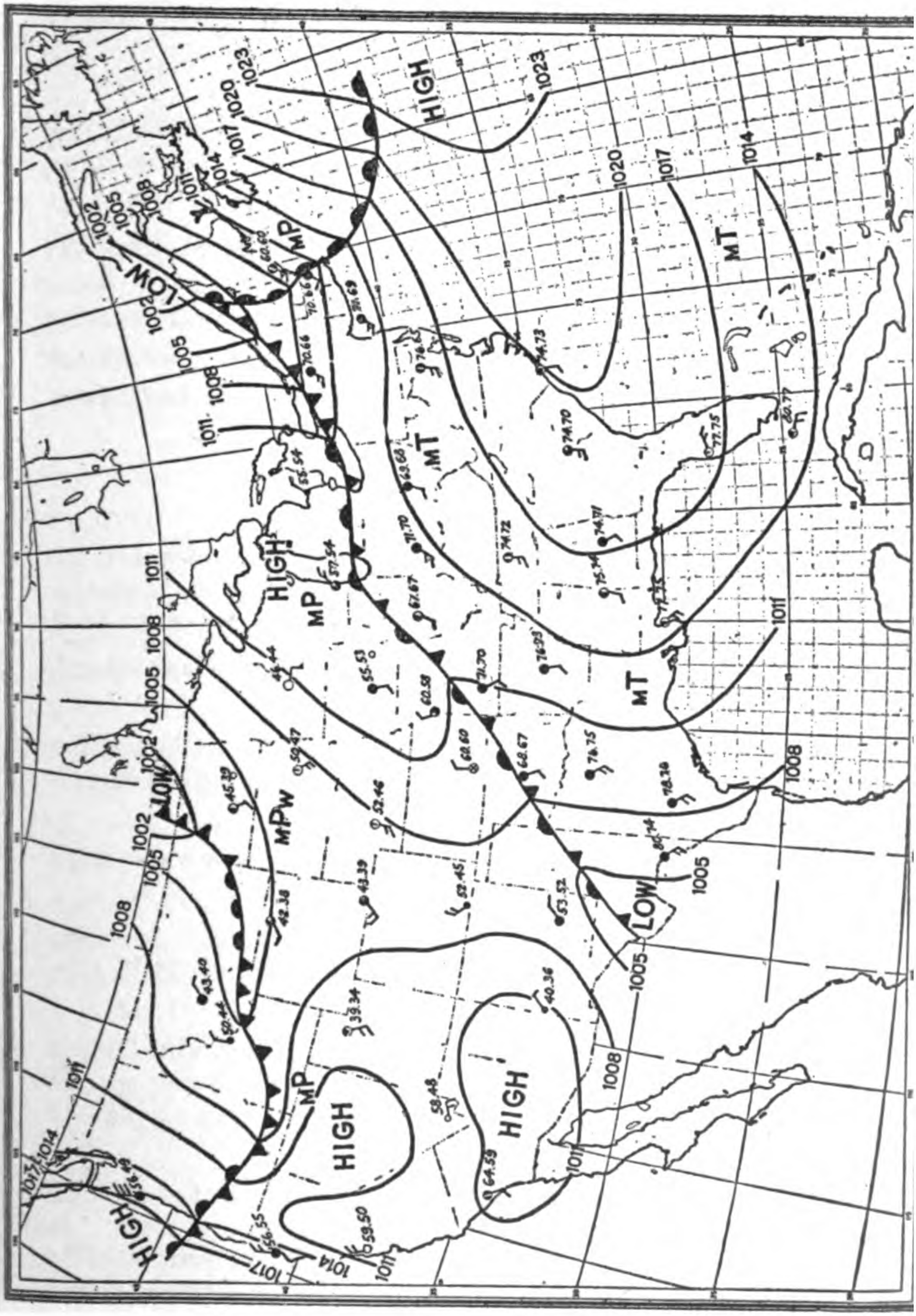
The recording barograph consists essentially of an aneroid barometer with a pen attached to the end of the pointer. As the pointer moves up and down with variations in air pressure, the pen traces a wavy line on a scale wrapped around a slowly revolving cylinder. The barograph provides a continuous record of atmospheric pressure over a period of hours, days, or an entire week. Sealed barographs have been used to verify the establisment of new altitude records.



Recording Barograph

In some work, pressure is expressed in **atmospheres.** An **atmosphere** is 14.7 lb./in.^{2} Thus a pressure of 10 atmospheres is 147 lb./in.^{2}

In meteorology, the millibar is often used as a unit of pressure. A **millibar** (mb) is 1,000 dynes/cm^2. At sea level,


HIGH
LOW
MP
MPw
MT
HIGH
LOW
HIGH
HIGH
HIGH
1002
1005
1008
1011
1014
1017
1020
1023

the normal atmospheric pressure is 1,013.2 mb. Thus a millibar is roughly $\frac{1}{1,000}$ of an atmosphere.

Isobars. On daily weather maps, lines are drawn which connect points of equal atmospheric pressure. These lines, called **isobars,** constitute a very important part of the map. Before observations are plotted, they are reduced to sea level. Weather maps often show an atmospheric pressure of more than 30 inches for El Paso, Texas, although the actual pressure recorded at El Paso is about 26.2 inches. To correct for elevation, about $\frac{1}{10}$ of an inch is added to the barometer reading for each 100 feet of elevation.

Exercises

1. A tank 4 ft. wide, 10 ft. long, and 5 ft. deep is full of water. If water weighs 62.5 lb./ft.^{3}, find the force exerted by the water on (a) the bottom of the tank and (b) at the 4 ft. by 5 ft. end of the tank.

2. Solve problem (**1**) if the tank is full of gasoline whose specific gravity is 0.7.

3. A raft is 4 ft. wide, 10 ft. long, and 8 in. thick. It is made of white pine whose density is 40 lb./ft.^{3} How much weight can the raft support in fresh water?

4. How far will the raft of problem (**3**) sink into fresh water when it carries no load?

5. The airship *R-100* had a gross weight of 150 tons. Assuming that it could float in an atmosphere whose density is .08 lb./ft.^{3}, find the volume of the airship.

6. A metal object weighs 27 g in air, 17 g in water, and 20 g in a liquid. Find the specific gravity of the object and the specific gravity of the liquid. Use your answers and the table on page 14 to identify the metal and the liquid.

7. Study the altimeter of a plane to see how many feet of altitude are represented by each of the smallest divisions on its scale. In laboratory practice, the reading of a scale should be estimated to $\frac{1}{10}$ of the smallest scale division. How many feet of altitude would

be represented by $\frac{1}{10}$ of the smallest division on the scale of the altimeter? To how many inches of mercury would this be equivalent?

8. Estimate the elevation of El Paso, Texas. Its actual elevation is 3,762 ft. in the business district.

9. Normal atmospheric pressure is 1,013.2 mb = 29.92 in. (of mercury). Use this equation to convert (a) 900 mb to inches and (b) 28 in. to millibars.

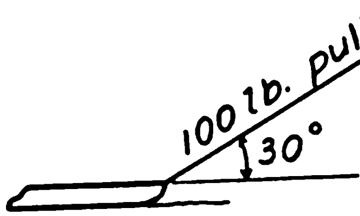
CHAPTER 6

Work, Energy, Power, and Friction

Work

The terms **work, energy,** and **power** are often misused in daily speech. **Work = force × distance.** The force and the distance through which the force moves must be measured in the same direction.

Work is most commonly expressed in **foot-pounds.** However, we can combine any unit of **force** with any unit of **length** to form a unit of work. An **erg** is the amount of work done when a dyne of force acts through a distance of 1 cm. Thus an erg is a **dyne-centimeter.** Because this unit is too small for convenience in many applications, the **joule** (10^7 ergs) is often used. The **kilowatt-hour,** which costs us from 3 to 5 cents, is 3,600,000 joules of work.



If a man lifts 20 lb. vertically upward for 5 ft., he does $20 \times 5 = 100$ ft.-lb. of work. If he carries a 100-lb. load about on a level field, he does *no* work. Suppose that a man pulls on a rope as indicated and drags the load forward for 20 ft. How much work does he do? Since the motion is in a horizontal direction, the work done = (the horizontal component of force) × 20 ft. The horizontal component of the 100-lb. force is 86.6 lb. Therefore the work = $W = 86.6 \times 20 = 1{,}730$ ft.-lb. The vertical component of force, 50 lb.,

does no work because there is no motion in the vertical direction.

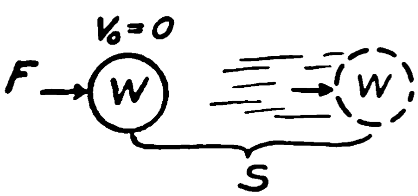
Energy

Energy is ability to do work. It is measured in units of work or in equivalent heat units. There are two kinds of energy: (1) potential energy and (2) kinetic energy.

Potential energy is energy due to **position** or to **internal strains.** If a 10-lb. object is 8 ft. above the floor, its P.E. is 80 ft.-lb.

Examples of P.E.: (1) A weight raised above the floor. (2) A wound-up clock spring, or a compressed automobile spring. (3) Chemical energy, as in fuel (1 lb. of average gasoline possesses about 16,000,000 ft.-lb. of potential energy).

Kinetic energy is the energy of an object which is due to the **motion** of the object. A moving object always does work when it is brought to rest. When the head of a hammer strikes a nail, work is done upon the nail. The kinetic energy of an object is equal to the work which the object does when it is brought to rest. It is also equal to the work which has been done to give the object its velocity. The formula by means of which the kinetic energy of an object may be calculated is obtained as follows:



Suppose that a constant force, F pounds, acts, through a distance, S feet, upon an object which is initially at rest. Then the work done on the object is

$$\text{K.E.} = W = F \times S \text{ ft.-lb.}$$

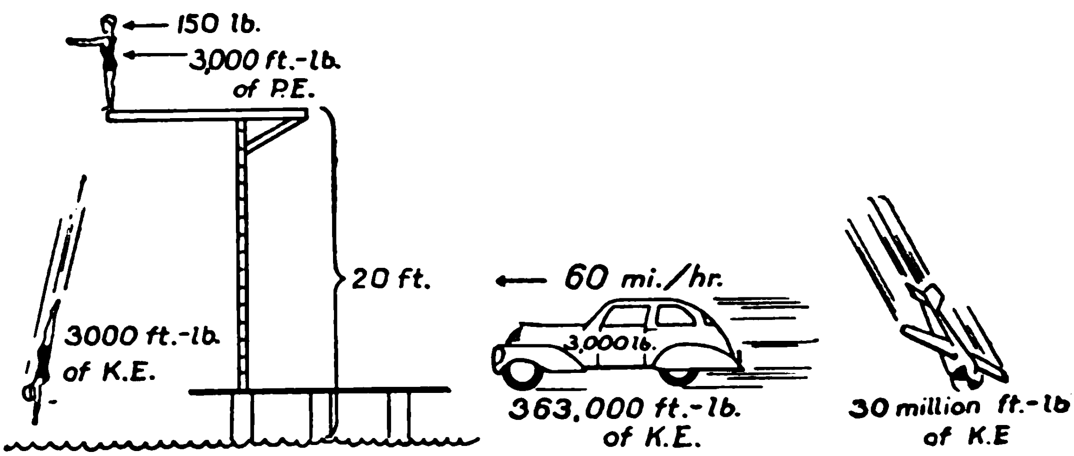
$$= \frac{w}{g}\, a\left(\frac{1}{2}\, at^2\right), \qquad \text{since } F = \frac{w}{g}\, a \text{ and } S = \frac{1}{2}\, at^2.$$

$$= \frac{w}{g}\frac{(at)^2}{2}$$

$$= \frac{wv^2}{2g} \text{ ft.-lb.}$$

$$\text{Thus K.E.} = \frac{wv^2}{2g},$$

Energy can be transformed from one form to another but it cannot be destroyed or created. This fact is known as the law of **conservation of energy.**



Examples of Kinetic Energy and of Potential Energy

Illustrations

1. If a 3,200-lb. auto is traveling at a rate of 90 ft./sec. (about 60 mi./hr.), its kinetic energy is K.E. $= \frac{wv^2}{2g} = \frac{3{,}200(90)^2}{2 \times 32} = 405{,}000$ ft.-lb. When the brakes are applied, the car is retarded by a force of 1,000 lb. In what distance, S, will the car be brought to rest?

$$\text{K.E.} = F \times S, \qquad 405{,}000 = 1{,}000S, \quad S = 405 \text{ feet.}$$

2. Suppose that a plane dives from a point, A, to a point, B, which is 900 ft. lower than A, and that the propeller thrust is just enough

to compensate for the energy which the plane would lose to air resistance. If the velocity of the plane is 60 mi./hr. at A, what velocity will it have at B? (This problem is equivalent to the problem of a sled which slides down a frictionless hill.)
Loss in P.E. from A to B = gain in K.E. from A to B.

$$w \times 900 = \frac{wv^2}{64} \text{ } (v = \text{gain in velocity.})$$

$$v = \sqrt{900 \times 64} = 240 \text{ ft./sec.}$$

$$= 164 \text{ mi./hr.}$$

and the final velocity = 60 mi./hr. + 164 mi./hr. = 224 mi./hr. Notice that the result is independent of the path which the plane takes from A to B.

Power

Power is the rate at which work is being done. In the British system, the units of power are the **foot-pound per second** and the **horsepower.**

1 hp. = 550 ft.-lb./sec. or 33,000 ft.-lb./min.

In the metric system, the units of power are the **watt** and the **kilowatt.**

1 watt = 1 joule/sec.
1 kilowatt (kw) = 1.3 hp., approximately.

Illustration

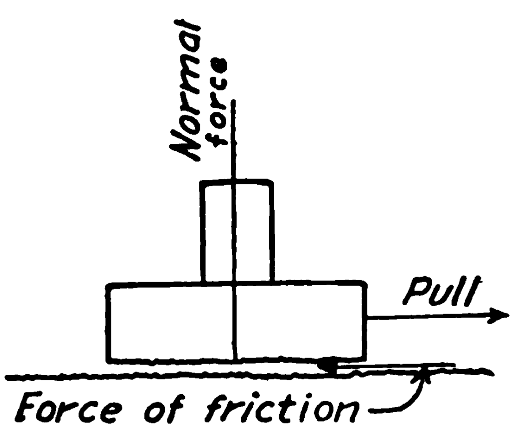
A 180-lb. man climbs a 20-ft. rope in 10 seconds. How much work does he do and what is his horsepower?

Work done = 180 × 20 = 3,600 ft.-lb.

$$\text{Power developed} = \frac{3{,}600}{10} = 360 \text{ ft.-lb./sec.} = \frac{360}{550} \text{ hp.}$$

$$= 0.655 \text{ hp.}$$

Friction



Whenever one surface slides over another, the motion is opposed by the force of friction. **Friction** is due to adhesion and to interlocking of the irregularities of the two surfaces. In a machine, friction causes wear, heating, and loss of power. Friction is reduced by proper design of bearings and by lubrication.

Laws of sliding friction.

1. Starting friction is greater than sliding friction.

2. Friction is less at high velocities than it is at low velocities.

3. The force of friction is independent of the amount of surface area if the force which presses the two surfaces together remains unchanged.

4. The force of friction is proportional to the normal force which pushes one of the surfaces against the other. This fourth law may be expressed as follows:

$$\text{Force of friction} = K \times (\text{normal force}),$$

$$\text{or } K = \frac{\text{force of friction}}{\text{force normal to surface}}.$$

The constant K is called the **coefficient of friction.**

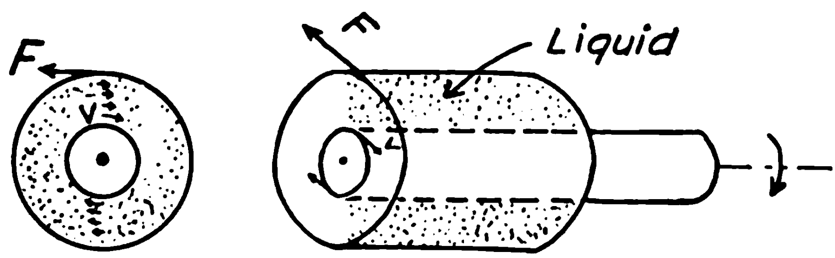
Coefficients of friction are obtained by means of very simple experiments. Suppose that some weights are put on a block of oak so that the block and its load have a total weight of 30 lb. If it takes a horizontal force of 10 lb. to keep the block sliding over an oak floor, at a constant speed, the coefficient of friction between the two surfaces is $\frac{10}{30}$ or $\frac{1}{3}$.

COEFFICIENTS OF FRICTION

Materials	K
Oak on oak	0.3 to 0.5
Iron on oak	0.6 to 0.65
Steel on ice	0.2
Iron on bronze (no lubrication)	0.25
Iron on bronze (lubricated)	.05 to .08

Usually we think of the undesirable effects of friction. However, friction performs many useful functions. Without friction we could not walk across a floor, belts could not be used to drive pulleys, ropes and thread could not be made, brakes and clutches would not operate. Anybody can think of many more instances in which friction is helpful.

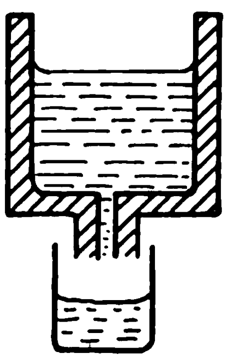
Viscosity is a frictional resistance offered by a fluid to the relative motion of its particles.



If a liquid fills the space between the two concentric cylinders shown, the rotating cylinder tends to impart its motion to the hollow cylinder. Thus the outer cylinder will be set in motion unless it is held back by the application of a force, F. The liquid touching the inner cylinder assumes the surface velocity of the inner cylinder and moves faster than any of the rest of the liquid. This inner layer slides inside the next layer and drags it along, and so on. The velocities of these layers of liquid vary as indicated by the arrows in the cross-section diagram. The layer in contact with the inner cylinder has the

greatest velocity and the layer in contact with the outer cylinder remains at rest. If the dimensions of the cylinders and the speed of rotation are given, the viscosity of the liquid can be measured by the magnitude of the force F. In laboratory practice the method indicated above must be modified slightly.

In industry, viscosity is measured by the number of seconds in which a given amount of the liquid will flow through a jet. The viscosimeter is calibrated so that determinations can be made quickly and easily.



Viscosimeter

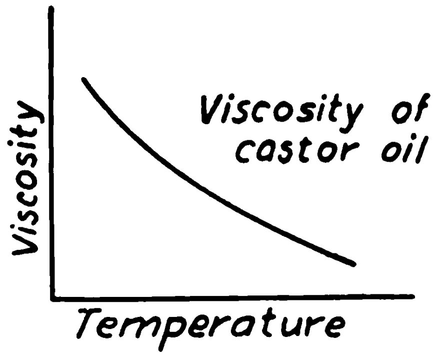
In practical tests on lubricating oils, the viscosimeter shown is placed in an oven to measure viscosity at high temperatures and in refrigerators to measure the viscosity of the sample at low temperatures. Most of us have heard such expressions as the "zero pour test."

Lubricating oils have been listed in order of increasing viscosity by the Society of Automotive Engineers (S.A.E.). The classification is given in the table. The remarks apply to use in automobiles.

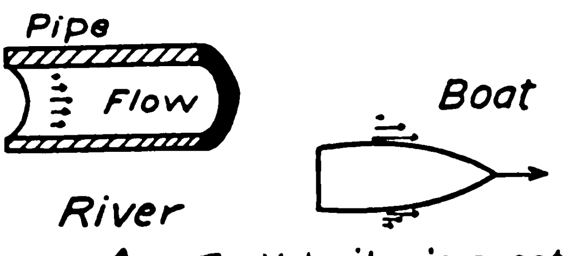
	S.A.E. Number		
For engine	10	Extra light (winter and breaking-in oil)	Viscosity very low.
For engine	20	Light	Viscosity very low.
For engine	30	Medium	Viscosity very low.
For engine	40	Heavy (for very hot weather	High viscosity.
For engine	50	Extra heavy (trucks and tractors)	High viscosity.
	90	Winter gear lubricant	High viscosity.
	150	Summer gear lubricant	High viscosity.

Most of us have noticed that liquids such as syrup or oils flow much more rapidly in summer than they do in winter. The viscosity of any liquid decreases markedly when the temperature is increased. Because of this fact, engineers have been

unable to find an ideal solution to the problem of lubrication of gasoline engines. If the engine oil is light enough to lubricate properly when the engine is cold, it becomes too thin after the engine has been warmed up. The oil actually used is too heavy to circulate properly while the engine is cold. To favor the engine as much as possible, it should be warmed up very carefully before it is given any great load.



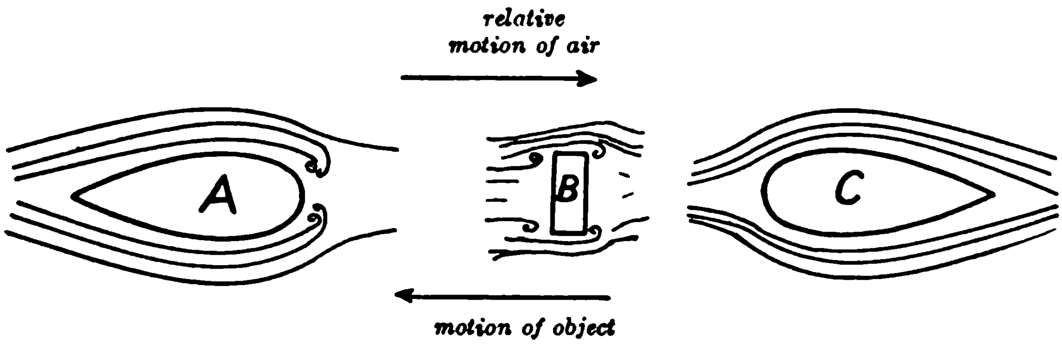
Effects of viscosity. Viscous friction is **proportional to velocity.** Because of the viscosity of **air, a** raindrop meets more and more frictional resistance as its speed increases. Finally the frictional force becomes equal to the weight of the drop. Then the forces acting on the raindrop are balanced and there is no further increase in velocity. The drop continues its fall with a constant velocity, which is called the **terminal velocity.** The terminal velocity is only one or two cm/sec. for very small drops. Thus droplets of water, as in clouds, remain suspended in air (or sink very slowly if the air is perfectly still), while large drops fall to the earth.



Velocity is greatest at A and is zero at shore and bottom.

Streamlining. Viscosity accounts for only a part of the air resistance encountered by trains, automobiles, and airplanes. At high velocities, much of the air drag is due to inertia of the air and to turbulence (swirls and eddies), and the total air resistance usually varies as the **square** of the velocity. **Drag,**

which is due to inertia of the air and to turbulence, is greatly reduced by streamlining. For a man falling without using his parachute, the terminal velocity is about 120 mi./hr. After the parachute opens, the terminal velocity is reduced to about 17 mi./hr.



Object "C" meets least air resistance

Exercises

1. How much kinetic energy does a 6,400-lb. airplane have when it is flying at a rate of 240 mi./hr.? How much potential energy does the plane have at an altitude of 15,000 ft.?

2. A 2-lb. hammerhead having a velocity of 6 ft./sec. strikes a nail. How much work is done upon the nail? If the blow drives the nail 1 in. into a plank, find the force with which the plank resists the progress of the nail.

3. If all the energy of gasoline could be used to do work, through what distance could the energy of 1 lb. of gasoline exert a force of 200 lb.?

4. A bomber releases a 4-ton "block buster" from the altitude of 10,000 ft. How much potential energy does the bomb have just after it is released, after it has fallen 8,000 feet, just before it strikes the ground? (Neglect the chemical energy of the bomb's explosive charge.) What additional information would we need if we wished to calculate the kinetic energy of the bomb at each of these points?

5. If a fly weighs 0.01 g, how many ergs of work does it do when it climbs 2 meters up a wall?

6. A French auto engine was rated at 15 kw. What was its horsepower?

7. A 150-lb. man runs up a stairway, raising himself 12 ft. in 4 seconds. What horsepower does he develop?

8. In the United States, the service ceiling of a plane is defined as the altitude at which the plane cannot climb more than 100 ft./min. How much reserve horsepower must a small 1,100-lb. plane have when flying at the service ceiling?

9. A tractor traveling at a rate of 4 mi./hr. can exert a pull of 1,000 lb. What is the drawbar horsepower of the tractor?

10. What horsepower is needed for a thrust of 200 lb. at 90 mi./hr. if (a) the thrust is in the direction of the flight path and (b) if the thrust makes an angle of 10° with the flight path? In (b) find the required component of thrust, graphically.

11. Why must the automobile engine be placed at the rear end if automobiles are to be streamlined? What should be done to the underside of the car? Which is more nearly streamlined, an airplane or an expensive automobile? Which of nature's creatures are most nearly streamlined?

12. Do you think that most of the air resistance at the angle between the hood and the windshield of a modern automobile is due to viscosity of air, to turbulence, or to overcoming the inertia of the air?

13. The lift on a plane varies as the square of the velocity. If the take-off speed of a 6,400-lb. plane is 60 mi./hr., how many pounds of the propeller thrust are needed to overcome the friction between the wheels and the surface of a field covered with long grass (a) when the plane just begins to roll, (b) when the velocity is 30 mi./hr., and (c) when the velocity is 60 mi./hr.? (Coefficient of friction = 0.1.)

14. At 30 mi./hr., 160 lb. of propeller thrust are needed to overcome friction between the wheels of a plane and the surface of a certain landing field. At this given speed, how much of the plane's horsepower is lost to ground friction?

Examination for Part One

1. Physics is a science whose purpose is to. . . . .

2. Meteorology is the science of. . . . .

3. A cyclone is. . . . .

4. The location of a cyclone is observed by. . . . .

5. The center of a cyclone travels from. . . . . . . .to. . . . . . . .across the U. S.

6. If the wind is from the west, an observer may expect that there is a low-pressure region to the. . . . . .of him.

7. The most important components of the atmosphere are (1). . . . ., ...%; (2). . . . ., ...%; (3). . . . ., ...%; (4). . . . ., ...%.

8. The temperature of the atmosphere drops about . . . . . .°F for every mile of altitude until a height of about. . . . . .mi. is reached.

9. The average atmospheric pressure, at sea level, is about. . . . . . lb./in.^{2}, and the barometer reads. . . . . .in.

10. Air weighs about. . . . . .as much as water.

11. The atmosphere is valuable to man because (1). . . . ., (2). . . . ., (3). . . . ., (4). . . . .

12. When the atmospheric pressure is 15 lb./in.^{2}, the force on a square foot of surface is. . . . . .lb.

13. 1 inch = ...cm; 1 foot = ...cm; 1 km = ... miles.

14. All measurements made by man may be reduced to measurement of one or more of these three things: (1). . . . ., (2). . . . ., (3). . . . .

15. The world standard of (1) is the. . . . ., of (2) is the . . . ., of (3) is the. . . . .

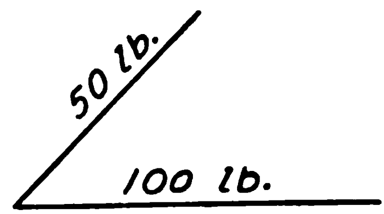
16. It is important to have world standards which are exactly defined because..

17. A vector quantity is one which involves................and ....

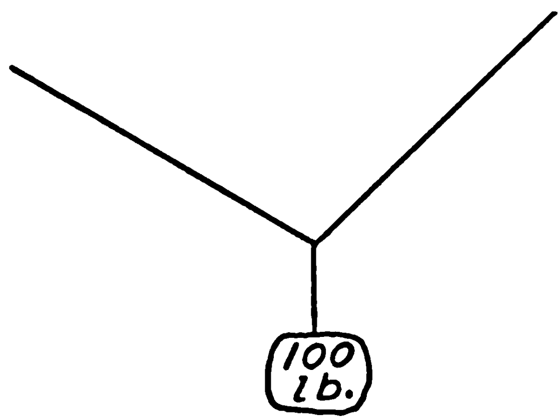
18. (1).............., (2).............., (3).............. are vector quantities.

19. A single force which will balance two or more forces is called the..........of these forces.

20. Find the resultant:



21. Find the tension in each inclined cord.



22. If an object falls from rest, it will drop......feet in 3 sec.

23. If an object is shot vertically upward with an initial velocity of 81 ft./sec. it will go up for......seconds.

24. The formula for centrifugal force, or for centripetal force, is C.F. =

25. The direction of centripetal force is........................ and the direction of centrifugal force is........................

26. The formula for momentum is M =

27. Impulse and momentum are related by the following equation .... = ...

28. If a pond is 10 ft. deep, the pressure on the bottom is...... lb./ft.^{2}

29. If the bottom of a tank is 15 ft. long and 10 ft. wide, the force on the bottom is.............

30. When an object is submerged in water, it seems to lose an amount of weight which is equal to the weight of...................

31. An isobar is...

32. The two kinds of barometers are the......barometer and the ......barometer.

33. If a 150-lb. man climbs a 20-ft. rope in 10 sec., he does........ of work and develops..........hp.

34. If a 320-lb. object has a velocity of 20 ft./sec., its kinetic energy is K.E. = ...

35. If it takes a force of 20 lb. to drag a 60-lb. object, the coefficient of friction is.............

36. Viscosity is..

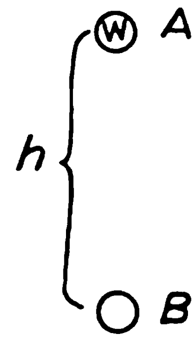
PART TWO

CHAPTER 7

Fluids in Motion

The velocity which an object gains in falling (from rest) through a distance, h, can be obtained as follows:

P.E. at A = K.E. at B (if no energy is lost through friction)



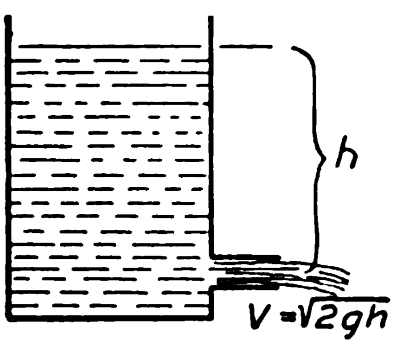
$$w \times h = \frac{1}{2}\frac{w}{g}v^2$$

$$v = \sqrt{2gh}$$

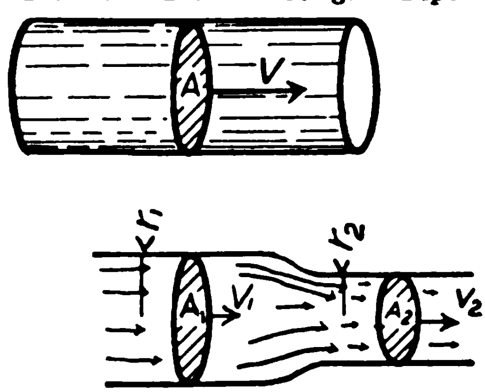
If $h = 100\,\text{ft.}, v = \sqrt{2 \times 32 \times 100} = 80\,\text{ft./sec.}$

By similar reasoning, it can be shown that the velocity with which a liquid will flow through a jet near the bottom of a tank is as indicated in the figure at the left.

Volume/sec. = (area of cross-section) × (velocity).

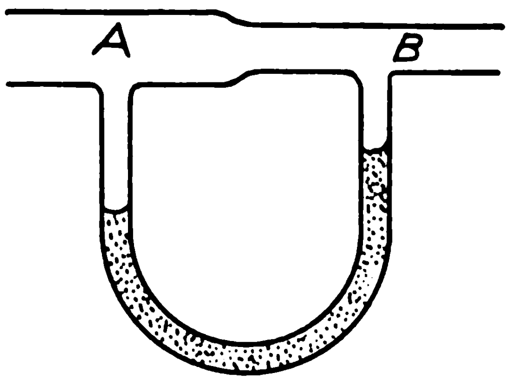


Flow of a Fluid Through a Pipe



When a fluid flows through two pipes of different sizes, as shown, volume/sec. equals $A_1v_1 = A_2v_2$. Therefore:

$\frac{v_1}{v_2} = \frac{A_2}{A_1} = \frac{r_2^2}{r_1^2}$, where r is the radius of a pipe and A is the area of cross-section of the pipe. Thus the speed of flow is greater in the smaller pipe.



Pressure Gage

Bernoulli's principle. Daniel Bernoulli (1700–1782) proved that wherever a fluid flows through a horizontal pipe system, the pressure plus the kinetic energy per unit of volume is the same at every point in the flow.

Thus:

$$P_A + \frac{\frac{1}{2}dv_A^2}{g} = P_B + \frac{\frac{1}{2}dv_B^2}{g}$$

or

$$P_A - P_B = \frac{\frac{1}{2}d}{g}(v_B^2 - v_A^2)$$

$g = 980$
$P =$ pressure in g/cm^2
$d =$ density (g/cm^3)
$v =$ velocity (cm/sec.)

Thus, **whenever a fluid is given an increased velocity throughout a certain length of its flow, the pressure at right angles to this velocity is reduced.** This statement is **Bernoulli's principle.** If the constriction is very small, the reduction in pressure is very great. In some applications P_A is more than one atmosphere and P_B is only a small fraction of an atmosphere.

Illustration

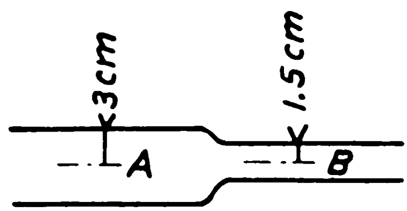
Water flows through the pipes shown at a rate of 9 liters/sec. What is the pressure drop from A to B?

$$v_A = \frac{9{,}000}{9\pi} = 318 \text{ cm/sec.}$$

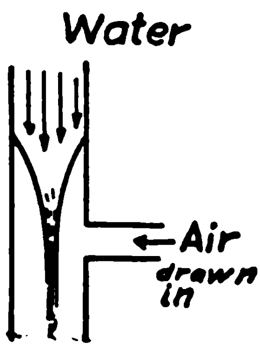
$$v_B = 4v_A = 4 \times 318 \text{ cm/sec.}$$

$$P_A - P_B = \frac{1}{2} \times \frac{1}{980} \times [(4 \times 318)^2 - (318)^2]$$

$$= 783 \text{ g/cm}^2.$$

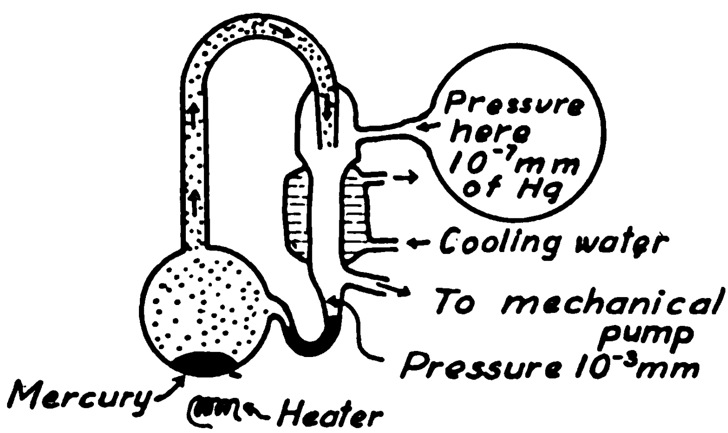


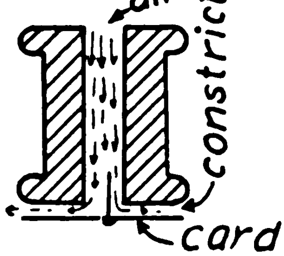
Applications of Bernoulli's principle.



1. **The sink aspirator** shown in the figure.

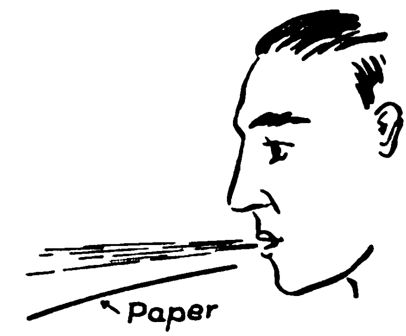
2. **The mercury vapor pump,** which is used in the manufacture of thermos bottles, radio tubes, X-ray tubes, and all other devices which require very high vacuums. This pump was invented by Irving Langmuir. It is made entirely of glass. With it, pressures as low as 10^{-7} mm of mercury may be obtained. 10^{-7} mm of mercury $= \frac{1}{7{,}600{,}000{,}000}$ of an atmosphere. Thus less than one molecule out of each seven billion remains after this pump has done its work. We know of no other pump which will produce so "good" a vacuum. Sometimes the mercury is replaced by oils of suitable physical properties.





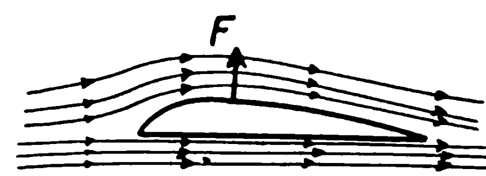
3. **The spool and card demonstration.** As one blows through the spool, the pressure under the spool is reduced because of the

directed velocity of the air, and the card is pushed to the spool by atmospheric pressure.



4. As one blows across the top of the paper, a reduction in pressure is produced and the paper is pushed upward.

5. **The airplane wing.** The airplane wing is affected very much like the paper in the above demonstration. Its aerodynamic design is based upon Bernoulli's effect. The wing is so formed that the air which flows over its top surface is made to travel over a longer path and thus at a higher velocity than the air which flows along its under surface. Thus there is a region of reduced pressure immediately above the wing. This area accounts for most of the lift. Thus the airplane in flight is supported by a force upon the top surfaces of its wings rather than by a push upon the under surfaces of the wings. When an accumulation of ice changes the shape of the airfoil, its lift may become so greatly reduced that the plane cannot be kept in flight even after the pilot has discarded enough of the plane's load to compensate for the added weight due to the ice.



6. **Other applications.** The Pitot tube for indicating air speed of a plane, the carburetor jet, and the atomizer depend upon the Bernoulli effect.

Exercises

1. A hole is drilled into a tank of water. If the hole is 9 ft. below the surface of the water, with what velocity will the water flow through the hole? If the area of the hole is .01 ft.^{2}, how much water will flow from the tank each second?

2. Water flows at the rate of 2 $ft.^3/sec.$ through a pipe. Find the velocity of the water in the pipe if the diameter of the pipe is (a) 4 in., (b) 2 in.

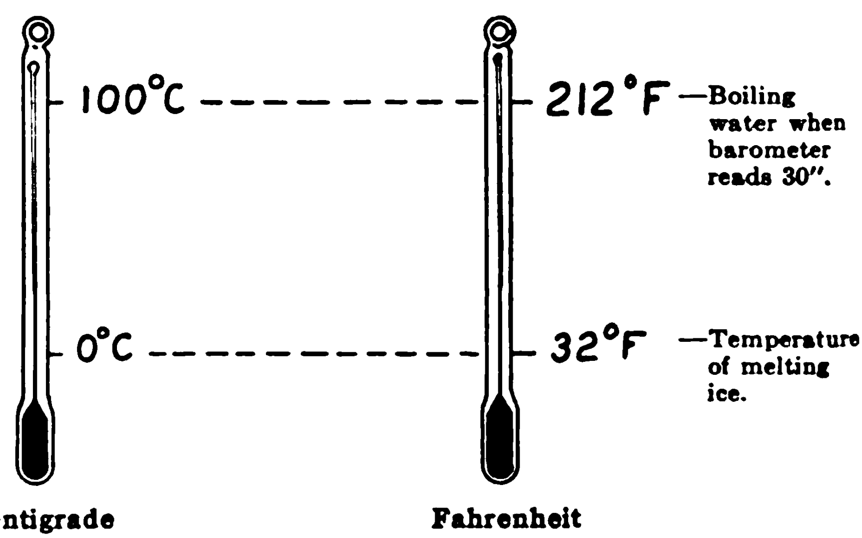
3. Examine the Pitot tube on a plane. How many holes are there along its circumference? Is it placed above the wing or below the wing? Why? Can you see any tubing leading from the Pitot tube to the instrument panel? How does the air speed indicator work?

CHAPTER 8

Heat

The molecules of any object are in a state of random motion. If the object is heated, this motion increases. **Temperature** is defined as the degree of this thermal agitation, or as the **degree of heat.**

The centigrade temperature scale is used in scientific work and in countries using the metric system. The Fahrenheit scale is used in daily life in countries using the foot, pound, and second system of measurement.



Observations may be converted from one scale to the other by means of the equation

$$°C = \tfrac{5}{9}(°F - 32).$$

Types of Thermometers

1. **Liquid-in-glass** thermometers usually contain mercury or alcohol.

2. **The resistance thermometer** is a small coil of wire, usually platinum, whose electrical resistance increases with temperature.

3. **The thermocouple** is made of two wires of unlike materials. The junction acts like a tiny electric cell whose voltage increases with temperature. These wires are connected to a sensitive voltmeter. The thermocouple is often preferred in industry and in engine testing.

4. **The automobile engine thermometer** is made of a metal bulb containing a liquid whose increase of pressure, due to heating, is transmitted to an instrument on the instrument panel.

Heat is a form of energy. It is measured in calories or in British thermal units (B.T.U.).

Heat Units

A **calorie** is the amount of heat needed to raise the temperature of 1 gram of water 1 degree centigrade.

A **B.T.U.** is the amount of heat needed to raise the temperature of 1 pound of water 1 degree Fahrenheit.

The **specific heat** of a substance is the amount of heat needed to raise the temperature of a unit of mass of a substance one degree. It may be expressed in calories per gram per degree centigrade or in B.T.U. per pound per degree Fahrenheit.

SPECIFIC HEAT: CALORIES PER GRAM PER °C OR B.T.U. PER POUND PER °F

Aluminum	0.21
Iron	.105
Copper	.093
Water	*1.

* From the definition of the calorie and the B.T.U.

Water has the greatest heat capacity of all the common substances. This fact is of great importance in the study of meteorology.

The Measurement of Heat

The most common way to measure a quantity of heat is to pass the heat into a known quantity of water and to measure the rise in temperature of the water. The heat gained by the water is equal to the mass of the water times its change in temperature.

The method of mixtures. The number of calories of heat gained or lost by any object is equal to mass × sp. ht. × change of temperature.

Suppose that we wish to determine the specific heat of a metal. The metal should be in small chunks. If we take 200 g of the metal, heat it to 100°C, drop it into 110 g of water contained in a copper cup weighing 90 g, and find that the temperature of the water rises from 10°C to 25°C, we can calculate the specific heat as follows:

Heat lost by metal

$$= \text{heat gained by water} + \text{heat gained by cup.}$$

$$200 \times \text{sp. ht.} \times (100 - 25)$$

$$= 110 \times 1 \times (25 - 10) + 90 \times .093 \times (25 - 10)$$

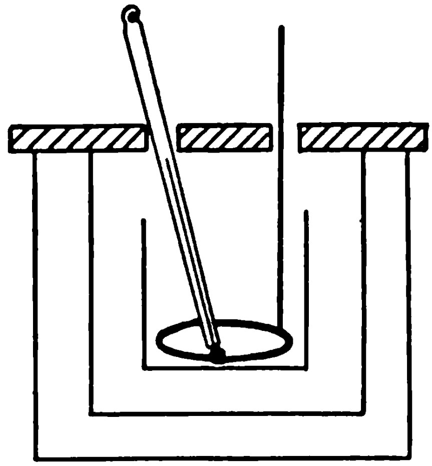
$$15{,}000 \times \text{sp. ht.}$$

$$= 1650 + 125.5$$

$$\text{sp. ht.} = \frac{1775}{15{,}000} = 0.119 \text{ calories per gram per °C.}$$

In this experiment, we have assumed that all of the heat lost by the metal is gained by the water, and that the water gains no heat from its surroundings.

To meet the requirements of this assumption, we try to have the initial temperature of the water as much below room tem-



A Calorimeter

perature as the final temperature will be above room temperature. As a further precaution, the cup is surrounded by a jacket, as shown, to reduce the heat exchange between the cup and the room.

The mechanical equivalent of heat. When 778 ft.-lb. of work are done against friction, 1 B.T.U. of heat is developed. Energy of any type could be expressed either in B.T.U. or in foot-pounds.

$$778 \text{ ft.-lb.} = 1 \text{ B.T.U.}$$

Heat of Combustion

The heat of combustion is the most import factor in determining the value of a fuel. It is defined as **the number of heat units given off when a unit of mass of the substance is completely burned.**

Substance	Heat of Combustion	
	Calories/gram	B.T.U./pound
Coal (anthracite)	7,600 to 8,400	13,500 to 15,000
Gasoline	11,000 to 11,400	20,000 to 20,500
Wood	4,000 to 4,500	7,000 to 8,000

Exercises

1. Convert 59°F to centigrade. Convert 60°C to Fahrenheit.

2. Experiments on gases indicate that no temperature can be lower than −273.18°C. Convert this to Fahrenheit.

3. How much heat is needed to raise the temperature of 300 lb. of iron from 70°F to 180°F?

4. A large air-cooled engine contains 1,100 lb. of iron, 300 lb. of aluminum, and 200 lb. of oil (sp. ht. = 0.5). How much heat is needed to warm this engine from 50°F to 180°F?

5. If 20,000 ft.-lb. of work are done against friction, how much heat is developed?

6. Two hundred grams of copper at 100°C are dropped into 100 g of water at 20°C. Neglecting the heat capacity of the container of the water, calculate the final temperature. (Use a heat equation like the one above.)

7. Solve exercise 69 on page 110 if the weight of the water is 90 g and the water is contained in a 100-g copper (sp. ht. = .095) cup.

8. How much gasoline would it take to supply as much heat as is needed in exercise 4?

CHAPTER 9

Heating of the Atmosphere

In our first lesson, we saw that the temperature of the atmosphere decreases about 16°F for each mile of elevation until a temperature of about −67°F is reached. Now we shall consider causes of these low temperatures at high altitudes. The atmosphere absorbs little of the sun's thermal radiation. Most of the heating of the atmosphere is due to **convection** and **conduction** of heat from the **earth**, which is heated by the sun. High altitudes, being far from the earth, receive very little of this heat. This fact causes a part of the great drop in temperature.

Another important cause is the fact that air, which rises from the surface of the earth, expands greatly upon reaching the regions of low pressure. Whenever a gas expands, its temperature drops unless it can gain heat from some source.

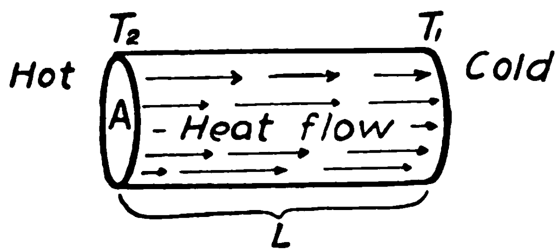
The reader may wonder why, if the absorption in the atmosphere is as small as indicated above, the atmosphere can prevent very high noon temperatures like those on the moon, which has no atmosphere. We owe much of our protection to the fact that about 37% of the sun's radiation is turned away from us by reflection and scattering by the atmosphere, and by clouds. Furthermore, the atmosphere permits convection currents which, during the hottest part of the day, carry tremendous amounts of heat up from the surface of the earth.

The Transportation of Heat

Conduction, convection, and radiation are the three ways in which heat is transferred from one region to another.

Conduction. If one sticks one end of an iron rod into a fire, the other end soon gets hot. With a silver rod, the same thing would happen even sooner, because silver is a better conductor of heat than iron.

Theory of heat conduction. When one end of a rod is heated, the motion of the molecules increases. In a solid, this molecular motion is confined to vibration of the molecules. The vibration of the molecules at the hot end of a metal rod sets the neighboring molecules in motion, and the process continues until the molecules at the far end have been affected. This molecular motion is **heat.**



The rate at which heat is conducted can be found by means of the following equation:

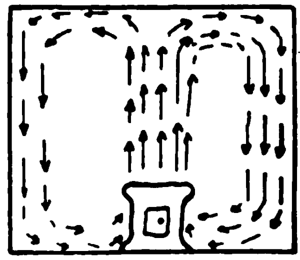
$$\text{Calories/sec.} = \frac{KA(t_2 - t_1)}{L}.$$

A (area) is in cm^2, t_1 and t_2 in degrees centigrade, and L in cm. The constant, K, depends upon the material. If K is large, the material is called a good conductor of heat. If K is very small, the material is called a good heat insulator.

Material	Thermal Conductivity, K	Material	Thermal Conductivity, K
Silver	0.974	Glass	0.0015
Copper	0.918	Paper	0.0003
Aluminum	0.504	Water	*0.0014
Iron	0.161	Air	*0.000052

* Special precautions must be taken in measuring the thermal conductivities of liquids and of gases; otherwise most of the heat will be transferred by convection.

Convection. If a house is heated by a stove, by a hot-air furnace, or by a hot-water furnace, most of the heat is transported from the heater to the living quarters by convection. The Model-T Ford relied entirely upon convection for the circulation of its cooling-water. If a room is heated by a stove, the convection currents are as shown in the figure. When air is heated, it expands and its density decreases. It is buoyed up by the heavier air around it. Cold air sinks, is heated, and rises.



Convection

Heating units should be placed as low as possible to permit free convection. The freezing unit in a refrigerator is always placed as high as possible.

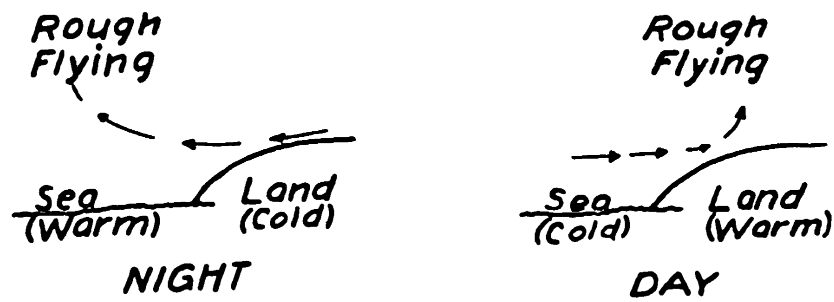
Radiation. The term *radiation* is often misused. An ordinary radiator does not do much radiating. It heats a room almost entirely by convection. Radiated heat can travel through free space. Its nature is much the same as that of light. Unless an object is very hot, it will not radiate much heat. At very high temperatures the amount of heat radiated becomes large. It has been found that

$$\text{Radiation per second} = C(t + 273)^4 \text{ calories.}$$

t is the temperature (centigrade) of the hot object. C is a constant which depends upon the nature of the surface of the object; it is small for a bright surface and large for a blackened surface.

Heat balance, daily variation. When the temperature of a region is constant, the region is losing heat as rapidly as it gains heat. The daily variation of temperature is reduced by the proximity of bodies of water. This is especially true if the prevailing winds are from the water to the land. Land breezes (night) and sea breezes (day) help to reduce daily

variation of temperature. They are due to the fact that land surfaces warm and cool more than surfaces of water. Rising air currents are strong over land in the daytime; strong over



water at night. Smoothest flying may be expected at night over land and by day over water.

Exercises

1. A copper rod is 10 cm long. Its area of cross-section is 2 cm^2. Find the number of calories per second which flow through the rod if one end is kept at 100°C and the other end is kept at 20°C.

2. A window 30 cm $\times$ 50 cm is glazed with 0.6-cm glass. The inside temperature is 20°C and the outside temperature is 0°C. How many calories of heat pass through the glass in 24 hours?

3. Why does a thermos bottle keep cold things cold better than it keeps hot things hot? Why is there very little convection over sea in the daytime? Why is there very little convection just above the tropopause (Fig. 1, page 4)?

4. If an object radiates 20 calories/sec. when the object is at 427°C, how many calories/sec. will be radiated when the object is at 1127°C?

CHAPTER 10

Properties of Gases

A gas always fills its container completely. A given quantity of gas does not have a definite volume; it assumes the volume of its container.

Gases diffuse rapidly. If a gas with a strong odor is released in one corner of a room, the odor can be detected, in a short time, at any point in the room. All gases are elastic and are easily compressed. The density of any gas is much less than that of any liquid or solid. Additional properties of gases will be described further on in this chapter.

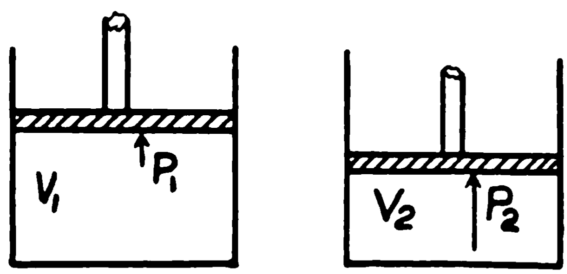
The Gas Laws

Boyle's law states that, if the temperature of a gas is kept **constant,** the volume of a given mass of the gas varies inversely as its pressure.

$$\frac{V_1}{V_2} = \frac{P_2}{P_1},$$

or

$P_1V_1 = P_2V_2$ (at constant temperature).



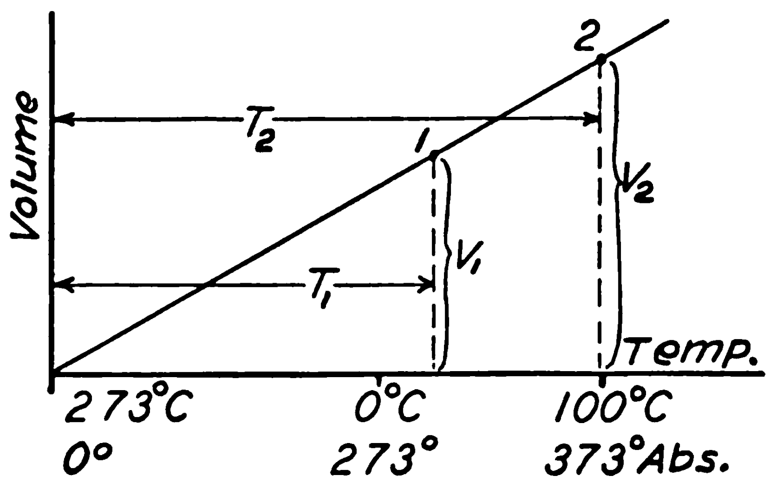
If $V_2 = \frac{1}{2}V_1$, $P_2 = 2P_1$.

In this and following formulas, V = volume; P = pressure; T = (absolute) temperature; d = density.

Charles's law. It is found by experiment that, if the pressure on a gas is kept constant, the volume of the gas increases $\frac{1}{273}$ of its volume at 0°C for each °C of rise in temperature.

When a gas is cooled down to the lowest temperatures commonly encountered, it behaves as though its volume would become 0 at −273°C (more exactly −273.18°C). This is known as the absolute zero of temperature. Theory indicates that it is impossible for any temperature to be less than absolute zero and that all linear motion of molecules ceases at absolute zero.

The absolute scale of temperature is commonly used in the study of gases. To convert from centigrade to absolute, add 273 to the centigrade temperature. From the graph, we can see that



$$\frac{V_1}{V_2} = \frac{T_1\ (\text{abs.})}{T_2\ (\text{abs.})}$$

Thus, if the **pressure of a gas is kept constant, the volume varies as the absolute temperature.** This is known as **Charles's law.** It may be shown that, if the **volume** is kept constant,

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}.$$

The general law of gases. Any problem involving Boyle's law or Charles's law may be solved by means of this general law: $P_1V_1/T_1 = P_2V_2/T_2$.

Since the density of a gas is inversely proportional to its volume, the gas laws may be written as follows:

$$\frac{d_1}{d_2} = \frac{T_2}{T_1}\ \text{(at constant pressure)},$$

$$\frac{d_1}{d_2} = \frac{P_1}{P_2} \text{ (at constant temperature),}$$

and
$$\frac{P_1}{d_1T_1} = \frac{P_2}{d_2T_2} \text{ (the general law).}$$

When Fahrenheit temperatures are given in problems involving the gas laws, it is more convenient to use absolute Fahrenheit temperatures than to use absolute centigrade as used above. To convert from Fahrenheit to absolute Fahrenheit, add 460 to the Fahrenheit temperatures. Thus, for constant pressure,

$$\frac{V_1}{V_2} = \frac{F_1 + 460}{F_2 + 460}, \qquad \text{or} \qquad \frac{d_1}{d_2} = \frac{F_2 + 460}{F_1 + 460}.$$

Illustrations

1. Aeronautical engineers consider 59°F (15°C) and 29.92 in. of mercury as standard conditions. Under standard conditions, the density of dry air is .0765 lb./ft.³ What is the density of dry air at 70°F and 22 inches of mercury?

$$\frac{29.92}{.0765 \times (59 + 460)} = \frac{22}{d_2 \times (70 + 460)}$$
$$d_2 = .0551 \text{ lb./ft.}^3$$

2. At 30°C and 15 lb./in.² of pressure, the volume of a gas is 5 ft.³ Find the volume of the gas when P = 30 lb./in.² and T = 10°C

$$15 \times \frac{5}{273 + 30} = 30 \times \frac{V}{273 + 10}$$
$$V = \frac{15 \times 5 \times 283}{30 \times 303} = 2.33 \text{ ft.}^3$$

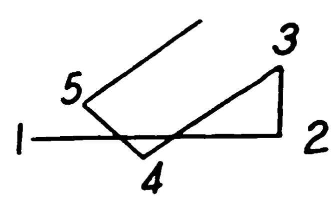
The Kinetic Theory of Gases

Early attempts to explain how a gas can exert a pressure were made on the assumption that the molecules repelled

each other and thus pushed the boundary layers of molecules against the walls of the container. Since the time of Isaac Newton, however, it has been known that "every object in the universe is attracted by every other object in the universe." The effects of surface tension are due to intermolecular attraction. Since molecules attract each other, the theory based upon repulsion had to be discarded. A vast amount of experimental evidence supports the modern theory which is known as **the kinetic theory of gases.** We shall consider a very brief outline of this theory.

According to the kinetic theory, the molecules of a gas are in a state of random motion. If we could watch an individual molecule, we would find that it travels with a constant velocity until it collides with another molecule. When it suffers a collision, the magnitude and the direction of its velocity are changed.

The path of the molecule might look about like this:



The wall of a container is hit many times per second. This bombardment results in a steady push upon the walls. The kinetic theory gives us an explanation of Boyle's law. If the volume of a gas is decreased, the number of molecules per cm^3 is increased, and there are more collisions per second on every unit of area of the container. Thus the pressure varies inversely as the volume.

If a gas is heated, its molecules move faster. Since they move faster, they hit the walls more frequently and are more effective when they do hit. Thus the law of Charles is explained by the kinetic theory.

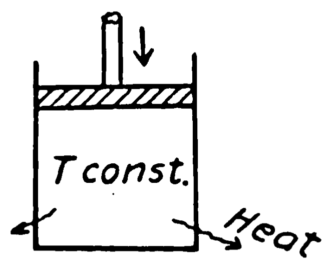
At 0°C, the mean velocity of the hydrogen molecule is 183,000 cm/sec. or 6,060 ft./sec. The mean distance traveled between collisions is .00002 cm under standard pressure. A molecule gets hit about 9,200 million times each second.

If two gases with different molecular weights are mixed, the heavier molecule has a mean velocity which is much smaller than that of the lighter molecule. As a gas is compressed, the molecules striking the advancing piston rebound with increased velocity. Increased molecular velocity means increased temperature. Thus a gas is heated when it is compressed. How would you modify these statements to explain how a gas is cooled when it expands?

Compression and Expansion of Gases

In the field of thermodynamics are two quite different kinds of processes which are very important in the study of heat engines and in meteorology.

An **isothermal process** is one in which the **temperature remains constant.** If the piston is moved down on the gas in the cylinder shown, work is done upon the gas. This means that heat is developed. If the temperature is to remain constant, the heat of compression must be dissipated as fast as it is generated. A perfect isothermal process is impossible, but the isothermal ideal may be approached if the compression is very slow and the cylinder walls are good conductors of heat. In an isothermal **expansion,** heat must flow **into** the cylinder to keep the temperature from falling. For an isothermal compression or expansion, the pressure and volume are related by this law: $PV = C$, C signifying a constant value. This is the same as Boyle's law.



ISOTHERMAL

An **adiabatic** process is one in which **no heat enters or leaves** the working substance. In an adiabatic expansion, the temperature falls; in an adiabatic compression, the temperature rises. The law relating pressure and volume

in an adiabatic change is $PV^\gamma = C$, or $P_1V_1^\gamma = P_2V_2^\gamma$. For air, the exponent, γ, is 1.403.

For a given change in volume, the change in pressure is more if the change is adiabatic than if the change is isothermal.*

Efficiencies of Heat Engines

The efficiency of an engine is $E = \dfrac{\text{output, or work done}}{\text{input, or energy taken in}}$.

By considering isothermal processes and adiabatic processes, Sadi Carnot (1796–1832), a brilliant young engineer of the French Army, proved that the efficiency of a heat engine cannot be more than

$$E_{(\text{maximum})} = \frac{T_2 - T_1}{T_2}.$$

For a steam engine, T_2 is the temperature of the steam entering the cylinder and T_1 is the temperature of the expanded exhaust steam. For a gasoline engine, T_1 is the temperature of the mixture in the cylinder at the beginning of the compression stroke and T_2 is the temperature attained at the end of the compression stroke as a result of the quick, adiabatic compression of the mixture. In Carnot's formula, all temperatures must be expressed in absolute centigrade degrees or absolute Fahrenheit degrees. Owing to friction and to heat losses, the efficiencies actually realized are about one half of Carnot's maximum efficiency.

For more than a hundred years, Carnot's expression has served as a guide to engineers who seek increased efficiencies of heat engines. Any increase in T_2 or any decrease in T_1 will result in greater efficiency.

The efficiency of a steam engine is increased if the steam is superheated before it enters the cylinder and by the use of

* See exercise 1 following.

multiple expansions and condensers to lower the temperature (T_1) of the exhaust. The degree of superheating is limited by the fact that steam, at high temperatures, exerts excessive pressures. Recently huge turbines have been built to use mercury vapor in place of steam. The vapor pressure of mercury is much less than that of steam. Thus mercury may be safely heated to very high temperatures.

In the internal combustion engine, nothing is done to reduce T_1, but T_2 is increased by use of a higher compression ratio. A high-compression gasoline engine takes in 6 volumes of air and gasoline vapor and compresses the mixture to 1 volume. Quick compression causes the temperature to rise to about 320°C. If the compression ratio is too great, the gasoline will ignite prematurely and cause a "knock." High-octane gasolines have been developed that make higher compressions possible without causing pre-ignition.

The Diesel engine should be regarded as an ultra-high compression engine. It commonly employs a compression ratio of 16:1. At this extreme compression, even the most advanced anti-knock gasoline would ignite long before the compression is completed.

Therefore, the Diesel engine compresses air only. The fuel is injected into the cylinder after the air has been compressed, and it burns upon contact with the air, whose temperature has been raised to about 1,000°F. The fact that the Diesel engine requires neither carburetor nor a spark is of relatively little importance. Its main advantage lies in its high efficiency, which is due to the very high temperature at the end of the compression stroke.

When Diesel engines were first offered for airplane use, they were advocated because the fuel they burn does not ignite very easily and thus the fire hazard is reduced. However, Diesel engines have certain characteristics which have

kept them from gaining much popularity among aeronautical engineers.

Adiabatic Processes in the Atmosphere

When perfectly dry air, rises and expands adiabatically, its temperature falls at a rate of 1°C for each 100 meters of its rise. (One hundred meters is the length of an average city block.) One degree C per 100 meters (5½°F/1,000 ft.) is said to be the **dry adiabatic lapse rate.**

If a mass of air rises in our atmosphere, why is its expansion very nearly adiabatic? We can give several good reasons: First, the atmosphere in which the mass rises is a poor conductor and radiator of heat. Second, the temperatures already existing at the higher altitudes are approximately equal to those which the mass would reach by adiabatic expansion alone. Third, the rising masses have very large volumes and their centers are far removed from the surrounding atmosphere. Thus the exchange of heat between the mass of air and the surrounding atmosphere is relatively small.

The moisture content of the atmosphere produces little effect upon the cooling due to expansion alone. However, when the air has reached some definite altitude, it has been cooled to a temperature at which it can no longer hold all of its moisture content. Some of its water vapor condenses to form the base of a cloud. As the air continues to rise, and to cool, its ability to hold water vapor is further reduced, and more condensation takes place.

When vapor condenses, heat is liberated. About 600 calories of heat are given off for each gram of water vapor which condenses. Thus, after condensation starts, the mass of air is heated by condensation of water vapor and cooled by further expansion, as the air continues to rise. This heat of condensation reduces the net lapse rate to 2° or 3°F per 1,000 feet. This is called the **moist adiabatic lapse rate.**

Exercises

1. Justify the statement marked (*) near the top of page 84.

2. From the data given in illustration 1, find the density of dry air at 29.92 inches of mercury and (a) 70°F, (b) 100°F.

3. Find the density of dry air at 59°F if the pressure is (a) 22 inches and (b) 26 inches of mercury.

4. A chemist collects 100 cm^3 of a gas at 20°C and 67 cm of pressure. What volume will this gas occupy under standard conditions (0°C and 76 cm of pressure)?

5. As a safety measure, small holes (vents) are made in the lower surface of an airfoil. If the volume enclosed by the fabric of an airfoil is 100 $ft.^3$, how many cubic feet of air flow out of the wing structure while the plane is rising from the earth where the pressure is 14.7 $lb./in.^2$ to an altitude at which the external pressure is 8 $lb./in.^2$? (Neglect the change in temperature.)

6. If the vents in exercise 5 were sealed so that the air could not escape, how much force due to pressure difference would tend to push the fabric of the lower surface away from the ribs? (Assume that the area of the lower surface is 80 $ft.^2$)

7. A radial engine, equipped with a rotary blower (supercharger), takes in 6 volumes of air and gasoline vapor at 27°C and 20 $lb./in.^2$ and compresses it to 1 volume at 297°C. What is the pressure at the end of the compression stroke?

8. (a) One cubic foot of air at 15 $lb./in.^2$ expands adiabatically to 2 $ft.^3$ What is the final pressure? ($2^{1.4} = 2.64$.)
(b) If the initial temperature of the air is 80°F, what will be the temperature after the expansion? (Use the result of (a) and the general gas law as it is used in illustration 1, page 81.)

9. How do we conclude that −273°C is the lowest temperature possible?

10. The velocities of the molecules of a gas are exceedingly great. How do you account for the fact that it takes several seconds for an odor to travel the length of a large room?

11. Some dry air rises 1,000 ft. over a mountain top and then sinks 600 ft. into a canyon. If the initial temperature of the air is 60°F,

what is its temperature at the top of the mountain and what is its final temperature? (Use the dry adiabatic lapse rate.)

12. If you want to fly as far as possible with a given amount of gasoline, should you choose an engine which occasionally exhibits a slight pre-ignition knock, or one which cannot be made to knock? Explain.

13. Which would be more apt to knock: an engine which is in good condition, or an engine which needs new piston rings? Explain.

14. Why is it true that carbon, deposited in the head of a cylinder, increases the compression ratio of an engine? How does this lead to pre-ignition knocks?

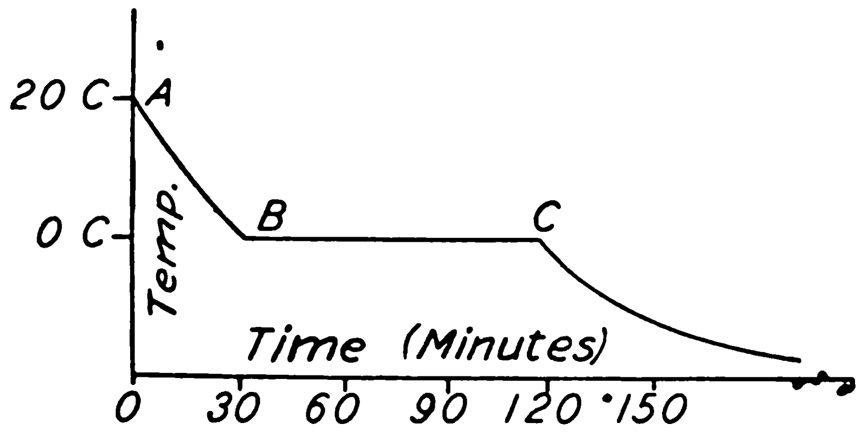
15. Carbon is a poor conductor of heat. How does this fact increase the likelihood of pre-ignition knocks?

CHAPTER 11

Change of State

Fusion and Freezing

On a cold day, when the outdoor temperature is several degrees below zero on the centigrade thermometer, it is possible to perform a simple experiment that will demonstrate some interesting and important facts. A can of water at 20°C is placed outdoors and the temperature of the water is observed every 5 minutes. It is important to remember that



Freezing of Water

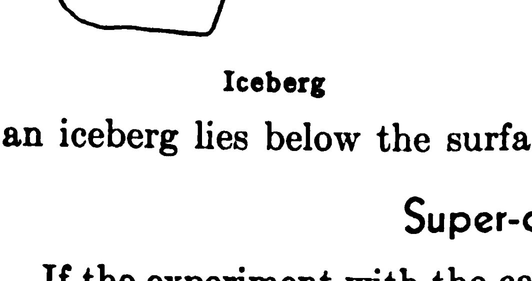
as long as the can and its contents are warmer than their surroundings, heat will flow out of the water. The observations are indicated by the graph of temperature, plotted as a function of time. At first, the temperature falls fairly rapidly until the water is cooled to its freezing point. At *B*, ice starts to form. Even though heat is still flowing from the can, the temperature ceases to fall. It does not fall below zero until all of the water has been frozen.

Then C is reached, and the temperature of the ice falls and gradually reaches the temperature of the surroundings. During the time from B to C, heat flows from the water; but the temperature of the water stays constant because 80 calories of heat must be given up by each gram of water at 0°C to change the water to ice. This heat, which causes no change in temperature, is called the **latent heat of fusion.**

The process may be reversed. In that case heat must be added to ice to cause fusion.

The **heat of fusion** of a substance is defined as the number of heat units required to change a unit of mass of the substance from the solid state to the liquid state **without causing a change of temperature.** The heat of fusion of ice is **80 calories per gram.** The heat of fusion of ice is usually measured by methods very much like those used in determining specific heats of metals. We may observe that the slope of the curve at C is about twice the slope at B. This difference is due to the fact that the specific heat of ice is only 0.5 calorie per gram per degree C.

Most substances shrink upon freezing. Water, however, expands when it changes to ice. This accounts for the bursting of pipes and radiators. Because the density of ice is 0.917 grams per cubic centimeter, ice floats in water. Eighty-nine per cent of the total volume of an iceberg lies below the surface of the sea.

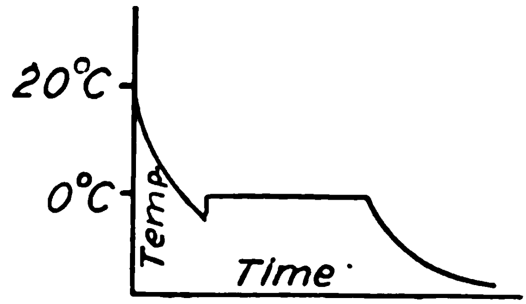


Iceberg

Super-cooling

If the experiment with the can of water is repeated in a very quiet place which is free from vibrations, the water may be cooled several degrees below its freezing point and will still

remain in the liquid state. This is an unstable condition; any slight vibration will cause a very sudden formation of ice. If the air dissolved in the water is removed by boiling or by putting the water under a partial vacuum, super-cooling is much more likely to take place. For this reason, the hot-water pipes in an unoccupied house are especially subject to damage by frost if the heating system is not kept in operation.



Super-cooling

Vaporization

Boiling. If heat is applied to water, the temperature of the water rises until the boiling point is reached. After this, the water will remain at a constant temperature regardless of the rate at which heat is supplied. If the burners are turned up, the water will be vaporized more rapidly. The **heat of vaporization** of a substance is the amount of heat required to change a unit mass of the substance from the liquid state to the vapor state **with no change of temperature.** When water boils at 100°C, its heat of vaporization is **539 calories per gram** or 970 B.T.U. per pound.

Evaporation. Boiling occurs only after the temperature of the liquid has reached the boiling point. Then the rate of boiling depends only upon the rate at which heat is applied. Evaporation takes place at any temperature of the liquid. Evaporation is quiet, and the vaporization takes place much more slowly than in boiling. The rate of evaporation is greatly affected by the degree of confinement of the air above the liquid and is greatly hastened by winds. Evaporation takes place rapidly in arid climates.

If some liquid is put into a closed container, molecules will go from the liquid to the space above it. This evaporation will continue until the space holds as much vapor as it can. The space is then said to be saturated with the vapor, and we say that a condition of equilibrium has been reached. Some molecules will still go from the liquid to the vapor, but an equal number will return from the vapor to the liquid. The number of grams of vapor that a unit volume of space can hold is called the **capacity.** It depends only upon temperature.

The **kinetic theory** leads us to expect that the vapor will exert a pressure which increases when density of the vapor increases. This expectation is confirmed by the experimental data given in the table below.

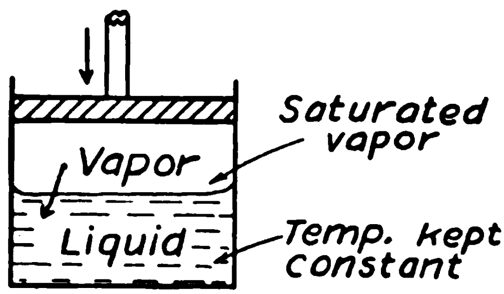
SATURATED WATER VAPOR

Temperature (°C)	Vapor Density (grams of vapor per cubic meter of space)	Vapor Pressure (mm of mercury)
−20	0.89	0.94
−10	2.2	2.0
0	4.9	4.6
10	9.4	9.2
20	17.3	17.4
30	30.4	31.8
100	598.0	760.0
120	1,122.0	1,491.0

The boiling point of a liquid is the temperature at which the vapor pressure is just enough to overcome atmospheric pressure. Then the fact that the space above the liquid is saturated will not prevent further vaporization. Thus our table can be used as an expression of the boiling point of water as a function of atmospheric pressure. From the table we can see that, if we wished to boil water at 20°C, we would have to reduce the pressure of the space above the water to 17.4 mm of mercury.

Dalton's law of partial pressures, as applied to our discussion, tells us that, if dry air and a vapor are mixed, each substance will exert its own pressure regardless of the presence of the other. Thus, if we have a closed tank of dry air at 760 mm of pressure and insert enough water to saturate the space in the tank, the total pressure will be 760 mm + 17.4 mm, or 777.4 mm, if the temperature is 20°C. If, at 20°C, the barometer indicates an atmospheric pressure of 673.3 mm and the air holds 50% of its capacity of water vapor, the pressure due to dry air alone is 673.3 − (50% of 17.4) = 664.6 mm.

To review some of the facts already considered, let us see what happens if we try to compress a vapor. When we bring the piston down, the pressure does not increase. Some of the vapor passes into the liquid state. This condensation would naturally warm the liquid because the latent heat of vaporization would be given off. If we want the liquid to remain at a constant temperature, this heat must be withdrawn by some method. The pressure will not increase until all of the vapor has been driven into the liquid.



If the piston is drawn upward, liquid will vaporize and the liquid will have to be heated if its temperature is to be kept constant.

Sublimation. Sublimation is a change from the solid state directly to the vapor state without going through the liquid state. You will notice that our table gives vapor densities and pressures for temperatures below 0°C. At these temperatures water exists either as ice as as a vapor, but not as a liquid (unless the water is in the unstable super-cooled condition). Under normal conditions, "dry ice" (solid CO_2), iodine crystals, and camphor sublime but do not melt or boil.

Exercises

1. If one blows much of the vapor out of a wide-mouthed bottle of ether, fixes a stopper firmly into the bottle, and shakes the bottle, a loud report is heard when the stopper is removed. In some trials, the stopper is blown out of the bottle. Use Dalton's law to explain this demonstration. *Hint:* How great is the pressure inside the bottle at the instant in which the stopper is inserted? For this demonstration, why is ether better than other liquids?

2. If a can of boiling water is sealed and allowed to cool, the can collapses. Explain this on the basis of vapor pressure and atmospheric pressure.

3. A room measures 8 m $\times$ 12 m $\times$ 3 m. The temperature of the room is 20°C. How many grams of water vapor are there in the room when the air contains 30% of its capacity for water vapor?

4. When water boils or evaporates at room temperature, its heat of vaporization is 585 calories per gram. An evaporation cooler evaporates 1 cm^3 of water each second. How many calories of heat does the cooler remove from the home each hour?

5. Increased vapor density does not account for all of the increase in vapor pressure which you will observe in the table of vapor pressure. What kinetic theory consideration accounts for the rest of the increase?

6. How much heat is needed to change 200 g of ice at 0°C to steam at 100°C?

7. A 500-g block of iron (sp. ht. = 0.1) is heated to 300°C and then placed upon a block of ice which is at 0°C. How much of the ice will be melted?

8. How many pounds of steam at 212°F must condense in a 200-lb. iron radiator to warm it from 40°F to 130°F?

9. In which is the water more apt to freeze: an auto radiator which has been freshly filled, or one which has been used without addition of water? If the water in each radiator does freeze, which radiator is more likely to be damaged? Explain.

CHAPTER 12

Atmospheric Humidity

In the Chapter 11, we saw that the amount of water vapor which a unit of volume of space, or air, can hold depends upon the temperature and increases greatly as the temperature rises. When the atmosphere holds as much water as it can at a given temperature, it is said to be **saturated.**

Capacity is the number of grams of water vapor per cubic meter that air or space can hold, at saturation. The column of densities in the table in Chapter 11 gives the **capacity** of space for water vapor at several temperatures.

Absolute humidity is the number of grams of water vapor actually present in each cubic meter of space. It may be equal to or less than the capacity.

$$\textbf{Relative humidity} = \frac{\text{absolute humidity}}{\text{capacity}}.$$

Relative humidity is the degree of saturation and is expressed in per cent. If air at 20°C contains 4 grams of moisture per cubic meter of space, the relative humidity is $\frac{4}{17.3} = 23.1\%$ (see table on page 92).

The dew point is the temperature to which the air must be cooled in order that the air be saturated. This condition is indicated by the condensation of vapor to form dew or frost. If the temperature is 20°C and the dew point is 0°C, it might

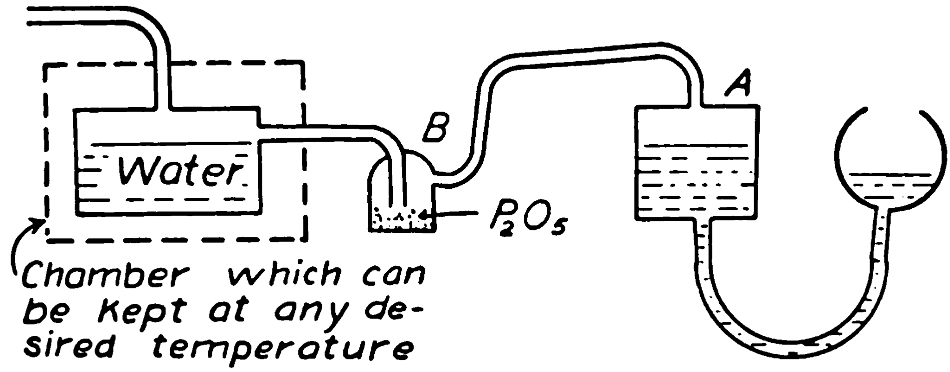
appear that the relative humidity is $\frac{4.9}{17.3}$ or 28.3%. However, a correction must be applied to the numerator. If a cubic meter of air were cooled from 20°C to 0°C, its volume would be decreased to $\frac{273}{293}$ of a cubic meter. Therefore, at 20°C, each cubic meter of air contains $\frac{273}{293} \times 4.9$ g, or 4.56 g, of water vapor. The relative humidity is then $\frac{4.56}{17.3}$, or 26.4%.

In winter the relative humidity in most homes is too low for comfort and health. As a furnace heats air, it increases its capacity and thus lowers the relative humidity unless some provision is made to add moisture to the air. The drying effect of air is determined by the relative humidity rather than by the absolute humidity.

Hygrometry

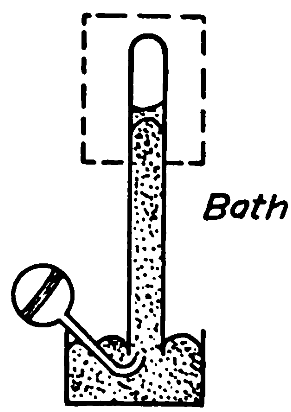
Hygrometry is the measurement of the moisture in the atmosphere. A **hygrometer** is an instrument used to measure atmospheric moisture. All humidity determinations made at weather stations require tables like the one given in Chapter 11, with an entry for each tenth of a degree, and other tables which are derived from this basic table. An immense amount of work was required in the establishment of these tables, but the technique involved is quite simple and direct. The chemical hygrometer and a vapor-pressure apparatus were used.

The **chemical hygrometer** is also known as the **absolute hygrometer.** The apparatus (page 97) needs little explanation. By lowering the liquid in *A*, the operator draws a known volume of saturated air through the drying chamber *B*. A very active drying agent absorbs the water vapor. The increase in weight of the drying agent measures the number of grams of water vapor in the saturated air. Very many repetitions of this experiment give us the density column of our tables.



The Absolute Hygrometer

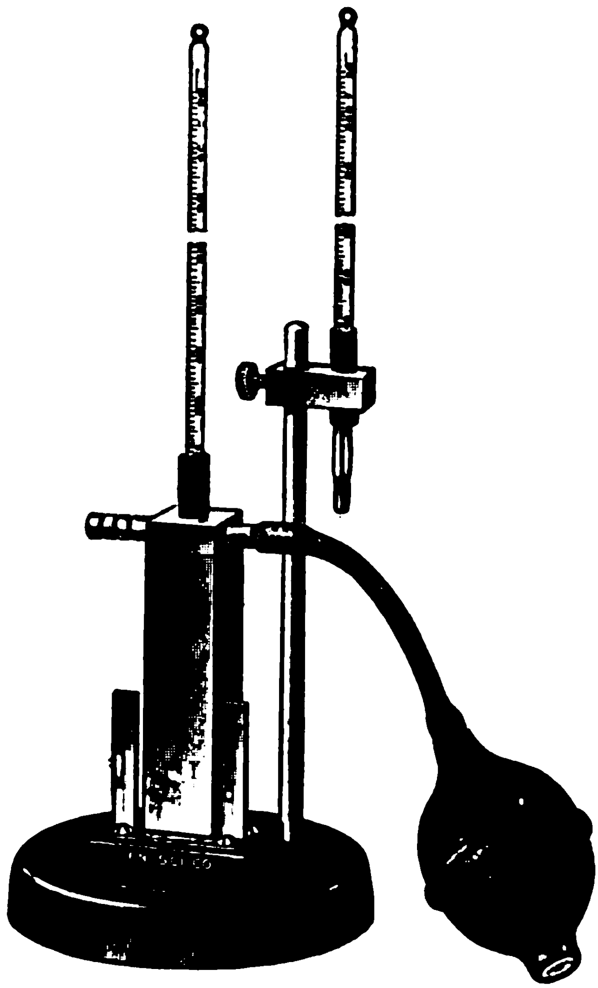
To determine saturated vapor pressures, a few drops of water are inserted above the mercury in a barometer. The difference between the reading of this barometer and the reading of a normal barometer indicates the vapor pressure. The bath is arranged so that the temperature of the liquid and the vapor can be kept at any desired value. Extensive tables of density and pressure of saturated water vapor expressed as functions of temperature are published by the Smithsonian Institution. The first edition was published in 1852.



Hygrometers in Daily Use

The **dew-point hygrometer** is a device for measuring the dew point. The Alluard type is shown on page 98. A nickel-plated container is partly filled with ether. Air is bubbled through the ether by means of an aspirator bulb. The container is cooled by the evaporation of ether until dew or frost forms on the front surface. After the dew appears, the operator can make it disappear or reappear at will. The temperature at which dew appears is a little below the dew point. The temperature of disappearance is a little above the dew point. The average of these two slightly different tempera-

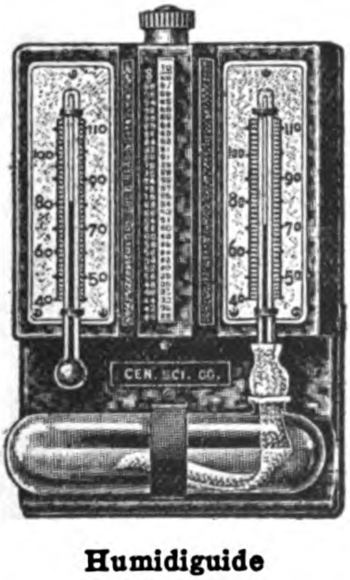
tures is taken as the true dew point. The absolute humidity and the relative humidity are calculated from the atmospheric temperature and the dew point by the method described earlier in this chapter.



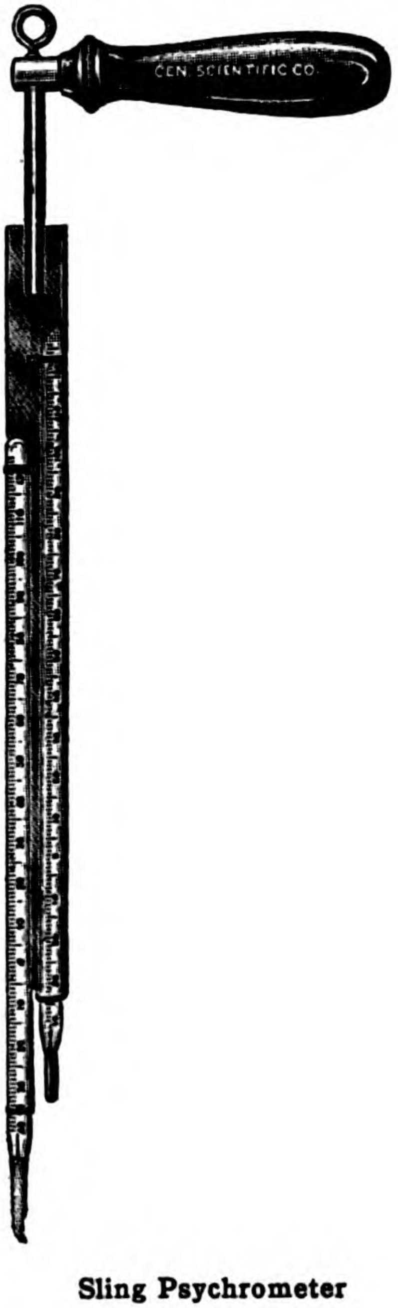
Dew-point Hygrometer

Wet-and-dry-bulb hygrometers are commonly used. Weather observers prefer the type known as the sling psychrometer. This device consists of two thermometers mounted so that they may be whirled in the air. The bulb of one of the thermometers is encased in gauze which is kept moist. This is the wet bulb. Evaporation cools the wet bulb.

The amount of cooling depends upon the dryness of the air. The apparatus is whirled until the temperature of the wet bulb



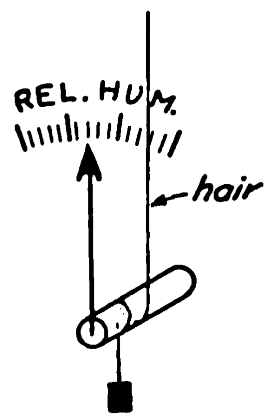
Humidiguide



Sling Psychrometer

no longer falls. From the temperatures indicated by the two thermometers, the relative humidity is calculated by means of tables. The Smithsonian tables are in general use in the

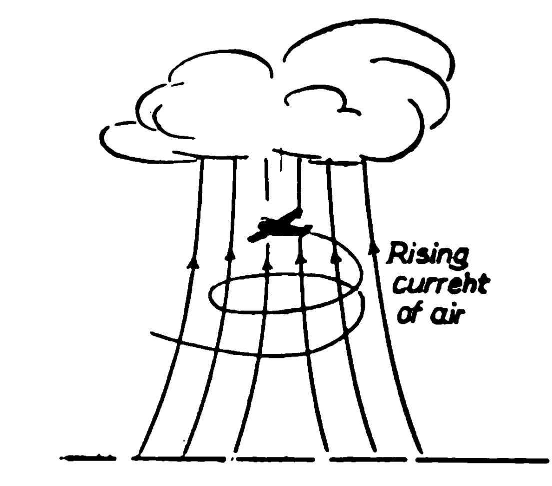
United States. Parts of them have been reproduced, by permission, in several manuals and handbooks.



Hair hygrometers depend upon the fact that, as a hair absorbs water, its length increases. This device indicates relative humidity directly, but it is usually unreliable unless it is calibrated very frequently by comparison with dew-point or wet-and-dry-bulb hygrometers. The hair hygrometer is used where the other types cannot be employed as in recording hygrographs and in the tiny radio apparatus which the Weather Bureau sends up with sounding balloons.

Clouds

Clouds are composed of very tiny droplets of water or, in the case of very high clouds such as the cirrus clouds, of very small ice crystals. The common cumulus (cū′mū lŭs) clouds look like collections of huge bolls of cotton and are often flat-bottomed. Frequently these clouds are the source of other types of clouds. They are of great importance in meteorology. A glider pilot often makes use of the fact that he may expect a rising current of air under a cumulus cloud, and can gain altitude by circling about in this upward stream of air. These rising columns of air are produced in three ways: (1) by winds



Glider Gaining Altitude

blowing against rising slopes of mountains, as on our West Coast, (2) by convection, (3) by warm, moist winds being forced to rise over cold, dense layers of air. Over much of the United States, the third cause is the most common. As the air rises, it cools, owing to expansion and to other causes which we considered in our study of the heating of the atmosphere. When the rising air has been cooled to its dew point, condensation begins. Condensation always occurs around some minute particle; usually a microscopic particle of dust or salt acts as the nucleus around which the vapor condenses. However, an electron or other electrical charge may act as the nucleus. If we watch the cloud chamber of an alpha ray track apparatus, we can see droplets, each of which has been condensed upon an electrically charged particle.

If, at the surface of the earth, the relative humidity and the temperature are known, the altitude of a cumulus cloud can be estimated. The method is explained in texts on meteorology.

The viscosity of the air keeps the droplets of a cloud practically in suspension, but it is not great enough to prevent the fall of raindrops, which are much larger than cloud droplets. However, air friction does limit the velocity which a raindrop gains in falling. Viscous friction is much more effective on small particles than it is on large ones. All of us have observed dust which remains suspended in the air, and we know that larger particles of the same material would fall rapidly. Careful studies of rates at which small particles fall through air have been vital to many discoveries in physics. Without this information Professor Millikan would have been unable to make his measurements of the charge on the electron.

There are several other types of clouds which the pilot must know. Their classification and their characteristics are studied in the course in meteorology that has been designed for pilots.

Exercises

(Use the table on page 92)

1. If the absolute humidity of a room is constant while the temperature increases, what change takes place in (a) the capacity, (b) the relative humidity, and (c) the dew point?

2. How many grams of water vapor are there in a room 20 m × 10 m × 4 m at 20°C if the relative humidity is 28%?

3. If the temperature of the room of exercise 2 is 20°C, how many grams of water must be evaporated in the room to raise the relative humidity from 20% to 33%?

4. On a certain day the outdoor temperature is 10°C and the dew point is 0°C. What is the relative humidity?

5. If the temperature is 30°C and the relative humidity is 31%, make a rough estimate of the dew point without correcting for the fact that air would contract when cooled from 30°C to the dew point.

6. Find the absolute humidity if the temperature is 0°C and the relative humidity is 35%.

7. Why is the difference between the wet-bulb temperature and the dry-bulb temperature governed by the relative humidity rather than by the absolute humidity?

8. If some moist air expands without losing any water vapor, what change occurs in the absolute humidity? How does the expansion affect the dew point?

9. Ordinarily, the relative humidity is high in the morning and becomes lower toward noon. Give two reasons for this decrease.

10. In the atmosphere, the dew point decreases about 0.2°C per 100 meters of ascent. Is this decrease due to the fall in temperature or to the increase in volume of the air? Explain.

11. The radiosonde sends signals to a receiving apparatus on the ground. The receiving apparatus then operates a mechanism which draws charts to show temperature and relative humidity at various altitudes. From these records, show how the dew point at each altitude could be determined.

12. If one cubic meter of air is saturated at 20°C, how many grams of its water vapor are condensed when the air is cooled (a) from 20°C

to 10°C, (b) from 10°C to 0°C, (c) from 0°C to −10°C, and (d) from −10°C to −20°C. Assume that the volume of the air does not change.

13. Considering your answers to exercise 12, what is the main cause of the uncertainty (2°F to 3°F) per 1,000 ft. in the moist adiabatic lapse rate?

14. At what altitudes would you expect the lapse rate to be 2°F/1,000 ft.? Where would you expect it to be 3°F/1,000 ft.?

15. On a certain day when the surface temperature is 70°F, the dry adiabatic lapse rate holds for the first 2,000 ft. Then condensation begins, cumulus clouds form, and the moist adiabatic lapse rate (average = 2.5°F/1,000 ft.) becomes effective. Find the temperature of the atmosphere at 2,000 ft. and at 12,000 ft. Draw a graph of temperature, plotted horizontally, against altitude, plotted vertically. (If a ruler is available, graph paper is not needed, because the graph consists of only two straight lines.) Between what two altitudes would clouds be composed of droplets of water? Beyond what altitude would clouds be composed of crystals of ice or super-cooled water droplets?

The graph shows how a rough approximation to actual conditions in the atmosphere are obtained from a few observations which are made at the surface of the earth. Actual lapse rates, recorded by means of radiosondes, are much more irregular than our simple graph.

16. A pilot notices that there are rising currents of air along a fairly well-defined line. He sees no rising slopes and can see nothing in the coverage of the earth beneath him which could account for his observation. The sky is cloudless even above the rising currents of air. What would he think was the cause of the vertical currents? What would you suspect as to the relative humidity when this effect is observed?

17. If the dew point at the surface of the earth is 10°C, what dew point would you expect at 5,000 ft.? at 10,000 ft.? In exercise 15, your graph shows the dew point at 2,000 ft. Draw a dotted line down from this point to the earth to show how the dew point varies with altitude. (See exercise 10.)

Supplementary Exercises

Chapter 1

1. Draw a large circle to represent the earth; on it indicate and name the various wind belts and calms.

2. Why do the western slopes of the Rockies get much rain while the eastern slopes are quite arid?

3. Define: *science*, *physics*, *meteorology*, *atmosphere*, *cyclone.*

4. Why are the westerlies of the southern hemisphere stronger and steadier than those of the northern hemisphere?

5. Describe the structure of the atmosphere.

6. What is the composition of the atmosphere? Name the four components which are most valuable to man.

7. What factors disturb the regular wind directions shown in figure 2 (page 6).

8. Sketch figure 2 as it would appear if the earth did not rotate.

9. What evidence shows that the atmosphere extends to a height of more than 700 miles? Why does the pressure of the atmosphere decrease with altitude? Why does the temperature of the atmosphere decrease with altitude? What causes the reversal of this change at the tropopause?

Chapter 2

10. What are the three fundamental magnitudes which are measured?

11. Give the definition of the standard for each of the three fundamental magnitudes. Name five derived units.

12. Find the number of square centimeters in a square inch. Find the number of cubic centimeters in a cubic inch.

13. A man weighs 180 lb. and is 6 ft. tall. Express his weight in kilograms and his height in meters.

14. Use the fact that 1 kg = 2.2 lb. to find the number of grams in 1 lb.

15. If a plane travels at 200 mi./hr., what is its velocity expressed in feet per second?

16. Las Cruces is 40 miles from El Paso. Express this distance in nautical miles. If a truck goes from El Paso to Las Cruces in 1 hour and 20 minutes, what is its average speed in miles per hour? in knots?

17. If a man runs at a rate of 100 yards in 10 seconds, how long will it take him to run 100 meters?

18. Define *density, specific gravity.*

19. A block is 10 cm long, 8 cm wide, and 4 cm thick. It weighs 1,500 g. Express its density in g/cm^3 and in lb./ft.^{3} What is the specific gravity of the material of the block?

20. A cylindrical tank is 30 in. long. Its radius is 10 in. How many gallons can the tank hold?

Chapter 3

21. What is force? What is a vector? What is a vector quantity?

22. What two kinds of motion are there? Name three vector quantities. Name some scalar quantities.

23. What is meant by composition of vectors? What is meant by resolution of a force? Give an application in which it would be helpful to resolve a force into components.

24. Define: *concurrent forces, resultant of several forces, equilibrant of several forces.*

25. A force of 200 lb. makes an angle of 40° with the horizontal. Find its horizontal component and its vertical component.

26. Find the magnitude and the direction of a force so that its horizontal component will be 80 lb. and its vertical component will be 100 lb.

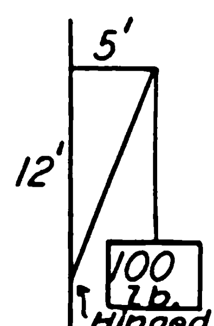
27. A board is 5 ft. long. One end rests on the ground; the other end is 3 ft. above the ground. A 100-lb. object rests on the board.

Resolve the weight of the object into a component parallel to the board and a component perpendicular to the board. Solve in two ways.

28. Find the resultant of each group of forces. When three forces are given, use the polygon method.

	F_1	F_2	F_3	Angle between F_1 and F_2	Angle between F_1 and F_3
a)	300 lb.	400 lb.		90°	
b)	100 lb.	120 lb.		50°	
c)	500 lb.	800 lb.		130°	
d)	100 lb.	200 lb.	150 lb.	40°	150°
e)	200 kg	100 kg	180 kg	100°	170°

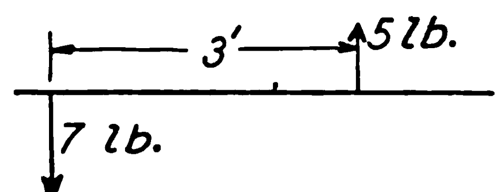
29. A 100-lb. object is suspended from a building by means of a rope. Find the angle which the rope makes with the side of the building when the weight is pulled away from the building by a horizontal force of 25 lb. *Hints:* The tension in the cord is the equilibrant of the other forces acting upon the weight. Make a second sketch from which the required angle may be found by means of a protractor.



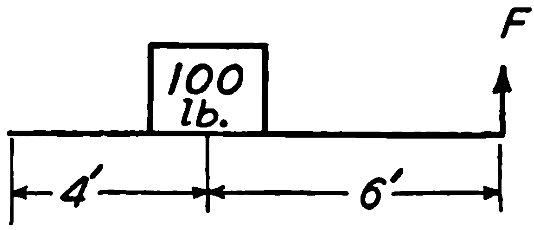
30. Find the force exerted by the horizontal cord and the push exerted by the rod. Neglect the weight of the rod. (Solve graphically and also by proportions.)

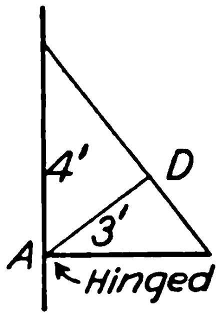
31. Define: *torque,* or *moment of force.* State the two conditions of equilibrium for vertical forces.

32. Find the equilibrant of the parallel forces shown.



33. The plank shown weighs 50 pounds. How much force, F, must a man be able to exert to raise the end of the plank from the floor?





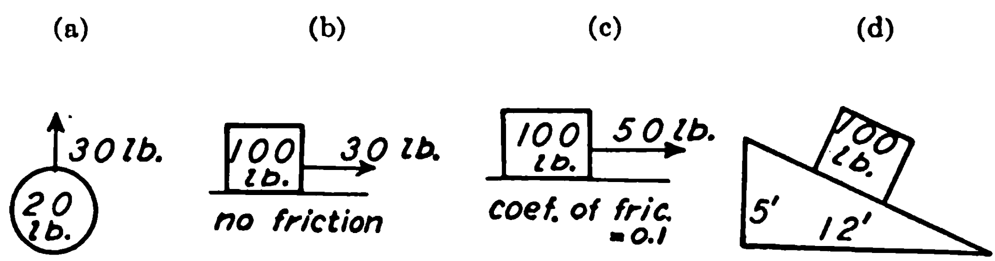
34. The horizontal rod weighs 100 lb. Find the tension in the inclined cord. (Find the length, AD, and then consider moments about A.)

Chapter 4

35. Distinguish between speed and velocity. State Newton's three laws of motion. Which of these three laws is used most frequently in the solution of problems involving forces and accelerations?

36. Define *acceleration.* Give an example of "action" and "reaction."

37. Find the acceleration in each case:



(Disregard friction in Fig. d.)

38. Complete the following equations as they apply to uniformly accelerated motion. If the initial velocity is not zero, $v =$ ________, $S =$ ________, and $v^2 =$ ________. If the initial velocity is zero, $v =$ ________, $S =$ ________, and $v =$ ________.

39. An object is dropped from a height of 100 ft. In how many seconds will it reach the ground? With what velocity will it strike the ground? What is the average velocity of the object during its fall?

40. An object is shot vertically upward with an initial velocity of 200 ft./sec. Where will it be at the end of 3 sec.? For how many seconds will it rise? How high will it rise?

41. A catapult 100 ft. long sends a naval plane into the air with a speed of 60 mi./hr. Find the acceleration of the plane while it is on the catapult, assuming that the acceleration is constant.

42. If the plane in exercise 41 weighs 4,800 lb., what force must the catapult and the propeller exert to give the plane the required acceleration?

43. How many seconds does it take for the plane to travel the length of the catapult?

44. A plane with a speed of 120 mi./hr. travels in a circular path whose radius is 1,000 ft. Find the centripetal force on the pilot if he weighs 160 lb.

45. An object is shot at an angle of 30° with the horizontal with an initial velocity of 200 ft./sec. Resolve the initial velocity into a vertical component and a horizontal component. For how many seconds does the object rise? How far horizontally does the object travel before it hits the ground?

46. From what height must an object be dropped so that its final velocity will be 100 ft./sec.?

47. Two skaters, a 150-lb. man and a 100-lb. boy, meet in a head-on collision. The man has been traveling 30 ft./sec.; the boy, at 40 ft./sec. They grasp each other when they meet. Find the magnitude and the direction of their common velocity after collision.

Chapter 5

48. Define pressure. Sketch and explain the aneroid barometer and the mercury barometer. Explain the advantages and the disadvantages of the mercury barometer.

49. A tank is 24 ft. long, 10 ft. wide, and 12 ft. deep. It is full of fresh water. Find the pressure due to the water on the bottom of the tank, the average pressure on the end of the tank, the force due to water pressure on the bottom, and the force due to water pressure on the 10 ft. $\times$ 12 ft. end of the tank.

50. An instructor in the U.S. Submarine Service made a record dive of 440 feet below the surface of the sea. The density of sea

water is 1.03 g/cm³. Find the pressure due to the water at this depth.

51. A barge is 12 ft. long, 6 ft. wide, and 2 ft. deep. It weighs 500 lb. To what depth will it sink into fresh water when it is empty? when it carries a load of 2,000 lb.? What maximum load can it carry if the top of the barge must remain 6 in. above the surface of the water?

52. State Archimedes' principle. An object weighs 20 g in air, 17 g in water, and 18 g in an oil. Find the specific gravity of the object and the specific gravity of the oil. What is the volume of the object?

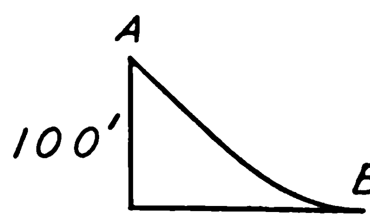
53. Convert 960 mb of pressure to g/cm², to inches of mercury, and to mm of mercury.

Chapter 6

54. Define: *work, energy, potential energy, kinetic energy, power, horsepower.*

55. A tractor traveling at a rate of 5 mi./hr. exerts a pull of 1,000 lb. on a scraper. What is the output horsepower of the tractor?

56. How many foot-pounds of kinetic energy does a 3,200-lb. automobile have when its speed is 45 mi./hr.?



57. A sled starts from rest at A. If no energy is lost due to friction, with what velocity will the sled reach B?

58. If a force of 30 lb. is needed to pull a 100-lb. object along a level floor, what is the coefficient of friction? Assume that the force acts in a horizontal direction.

59. A force of 20 lb. acts on a 100-lb. object initially at rest. Find the final velocity (a) if the force acts for 5 sec., and (b) if the force acts through a distance of 20 ft.

60. Find the answer to exercise 42 by use of the equation $FS = \frac{wv^2}{2g}$.

Chapter 7

61. State Bernoulli's principle. Name four demonstrations or applications of the principle and explain how one of them works.

62. How many cubic feet of water will flow through a round hole in the bottom of a tank if the hole is $\frac{1}{2}$ in. in diameter and the depth of the water in the tank is kept at 16 ft.?

Chapter 8

63. The melting point of tin is 232°C. Convert this temperature to Fahrenheit. The normal temperature of the human body is 98.6°F. Convert this to centigrade.

64. Upon what physical fact is the operation of the liquid-in-glass thermometer based? Define: *heat*, *calorie*, *B.T.U.*, *specific heat*.

65. How many calories of heat are needed to raise the temperature of 120 g of aluminum from 20°C to 100°C? How much water would be heated from 20°C to 100°C by this same number of calories?

66. Two hundred grams of water are contained in a 100-g iron cup. How much heat is needed to raise the temperature from 20°C to 40°C?

67. In the preceding exercise, if the masses were 200 lb. and 100 lb. respectively, and the required increase in temperature were from 20°F to 40°F, how many B.T.U.'s of heat would be required?

68. Suppose 150 g of lead (sp. ht. = 0.03) at 100°C are dropped into a 90-g brass (sp. ht. = 0.09) cup containing 80 g of water at 10°C. Calculate the final temperature.

69. If 200 g of a metal at 100°C are dropped into 100 g of water at 10°C, the resulting temperature is 25°C. Calculate the specific heat of the metal. (The heat capacity of the container of the water is so small that it may be neglected.) *Ans.* 0.1 calorie/gram/°C.

Chapter 9

70. Name some of the causes of the great decrease in atmospheric temperature with altitude.

71. By what means can heat pass through a perfect vacuum? How could you make it possible to see convection currents in a room?

72. Why are furnaces put in basements rather than in attics? Why is ice placed in the *upper* part of the cabinet of a refrigerator?

Would the ice last longer if it were placed in the bottom of the cabinet? Explain.

73. Explain the manner in which sea breezes and land breezes are produced. During the daytime, would you expect bumpy flying over very dry land or over a surface covered with heavy vegetation? Explain. Show how night flying over these two surfaces would compare.

Chapter 10

74. State Boyle's law, Charles's law, the general gas law. How do we reach the conclusion that $-273°C$ is the absolute zero of temperature?

75. An automobile tire contains 2,000 in.^{3} of air at a *gage* pressure of 30 lb./in.^{2} What volume does this air occupy if it expands to atmospheric pressure? Assume that atmospheric pressure = 15 lb./in.^{2}

76. An automobile tire at 27°C contains air at 30 lb./in.^{2} above atmospheric pressure, which is 15 lb./in.^{2} Find the pressure of the air in the tire if the temperature rises to 47°C (116.6°F).

77. A chemist collects 100 cm^3 of hydrogen at 27°C and 70 cm of pressure. What volume will this gas occupy under standard conditions (0°C and 76 cm of pressure)?

78. How did Newton's law that "every object in the universe is attracted by every other object in the universe" affect man's ideas as to how a gas exerts a pressure?

79. What is an isothermal process? What is an adiabatic process?

80. Air at a pressure of 100 lb./in.^{2} and a volume of 10 in.^{3} expands to a volume of 20 in.^{3} Find the final pressure (a) if the expansion is isothermal and (b) if the expansion is adiabatic. ($10^{1.4} = 25$ and $20^{1.4} = 66$.)

81. Write down each of the following statements as it should be completed. A very slow expansion is apt to be. . . . . A very quick expansion is apt to be. . . . . In an adiabatic expansion the temperature of the gas. . . . . . In an adiabatic compression, the temperature. . . . .

82. Define: *heat of fusion, heat of vaporization, super-cooling.* The heat of fusion of ice is. . . . . per . . . . The heat of vaporization of water is . . . . .per . . . .

83. The three states in which water may exist are.........., ..., and...........

84. A 25-g cube of ice at 0°C is put into 200 g of water at 30°C. Calculate the final temperature. (Neglect the heat capacity of the container of the water.)

85. Five grams of steam at 100°C are condensed in 200 g of water at 20°C. Calculate the final temperature.

86. A 400-g block of iron is heated to 300°C and placed on a block of ice which is at 0°C. How many grams of ice will be melted?

87. With reference to atmospheric humidity, define: *capacity, absolute humidity, relative humidity, dew point.*

88. Why is the decrease in temperature of a wet bulb an indication of relative humidity? How does the dew-point hygrometer enable one to find the dew point?

89. Very commonly, the water content of clouds is super-cooled below 0°C. How does this fact introduce dangers to aviation?

90. The temperature of a room is 20°C and the absolute humidity is 5 g of water vapor per cubic meter. What is the relative humidity?

91. What is the relative humidity of a room if the temperature is 20°C and the dew point is 0°C?

92. Sketch and name three different types of hygrometers which are in daily use. Why is the absolute hygrometer not used by weather observers?

93. If the temperature of a tightly closed room is increased, what change occurs in the absolute humidity, the capacity, the relative humidity, the dew point.

94. Name the three factors which determine the altitude of the base of a cumulus cloud. Of what is a cumulus cloud composed? Of what is a cirrus cloud composed?

95. Water vapor is invisible. Would you call the collection of droplets which we see at the spout of a kettle fog, dew, haze, mist, or a cloud? In a recent "quiz program" frost was defined as frozen dew. Why is this definition incorrect?

96. As moist air rises from the surface of the earth, more and more of its vapor condenses. Which would be cooled more in rising quickly, moist air or dry air? Explain.

97. On a hot day, would a glider pilot have a better opportunity to maintain altitude over dry land or over water? Explain.

Answers to Questions and Problems

Answers are mostly to odd-numbered numerical exercises. A few other answers are given when it is deemed advisable.

Page 11

6. −45°F, 9 in., −60°F, 1.2 in. **9.** 2,025 lb., 62.9 slugs.

Pages 16–17

1. 7.48 gallons. **3.** 30.48 cm. **5.** 20.45 mi./hr. **7.** 48 km/hr., 25 mi./hr., 9.4 gallons. **9.** 21,600 nautical miles. **11.** Multiply 62.5 by the specific gravity. **15.** 58.67 ft./sec., 102.67 ft./sec.
17. .0765 lb./ft.^{3}, .00122 g/cm^3.

Pages 24–25

3. Approximately 53 lb. and 84 lb. **5.** 38.5 lb., 92.3 lb.
7. 14.5° north of east, 140 mi.

Pages 28–29

1. 6.9 ft. from center. **3.** 5.5 tons and 6 tons. **7.** 54.16 lb.
11. 166 lb., 2,174 lb. **13.** 166.7 lb. up.

Pages 38–42

1. 2 ft./sec., 38 ft./sec., 3,800 ft./sec./sec. **3.** 8 sec. **5.** 688 lb.
7. 7.7 lb., 12.3 ft./sec./sec. **9.** 20 mi./hr. **11.** 466.6 ft.
13. 25 sec. **15.** 87.8 ft. **17.** 29 mi./hr. **19.** 15,000 lb. **21.** 193.6 ft.
23. 1.41w. **27.** 125 ft. **29.** 3 sec., 144 ft., 300 ft.

Pages 50–51

1. 12,480 lb., 3,120 lb. **3.** 597 lb. **5.** 3,333,000 cu. ft.
9. 26.58 in., 948.2 mb.

Pages 60–61

1. 12,390,000 ft.-lb. **3.** 80,000 ft. **5.** 1,960 ergs. **7.** $\frac{2}{11}$ hp.
9. $10\frac{2}{3}$ hp. **13.** 640 lb., 160 lb.

Pages 68–69

1. 24 ft./sec., 0.24 ft.^{3}

Pages 73–74

1. 15°C, 140°F. **3.** 3,465 B.T.U. **5.** 25.7 B.T.U.
7. .0995 calorie/gram/°C.

Page 78

1. 14.7 calories/sec. **4.** 320 calories/sec.

Pages 87–88

3. .0562 lb./ft.^{3}, .0665 lb./ft.^{3} **5.** 83.75 ft.^{3} **7.** 228 lb./in.^{2}
11. 54.5°F., 57.8°F.

Page 94

3. 1,494.7 g. **5.** Increased velocity of the molecules of water vapor at the higher temperatures. **7.** 187.5 g.

Pages 102–103

1. increases, decreases, remains unchanged. **3.** 1.799 kg. **5.** 10°C.
12. 7.9 g, 4.5 g, —, —.
15. 59°F, 34°F, from 2,000 ft. to 12,800 ft., above 12,800 ft.
17. 6.95°C, 3.9°C.

Pages 104–112

13. 81.8 kg, 1.83 m. **15.** 293 ft./sec. **17.** 10.9 sec.
19. 4.69 g/cm^3, 293 lb./ft.^{3} **25.** Approximately 153 lb. and 129 lb.
27. 60 lb., 80 lb. **29.** 14°. **33.** 65 lb. **37.** 16 ft./sec./sec., 6.4 ft./sec./sec., 12.8 ft./sec./sec., 12.3 ft./sec./sec.
39. 2.5 sec., 80 ft./sec., 40 ft./sec. **41.** 38.7 ft./sec./sec.
43. 2.27 sec. **45.** 100 ft./sec., 173 ft./sec., 3.13 sec., 1,081 ft.
47. 2 ft./sec. in the direction in which the man was going.
49. 750 lb./ft.^{3}, 375 lb./ft.^{3}, 180,000 lb., 45,000 lb.
51. 1.33 in., 6.67 in., 6,250 lb. **53.** 979.6 g/cm^2, 28.35 in., 720.1 mm.
55. 13.33 hp., **57.** 80 ft./sec. **59.** 32 ft./sec., 16 ft./sec.
63. 449.6°F, 37°C. **65.** 2,016 calories, 25.2 g. **67.** 4,210 B.T.U.
75. 6,000 in.^{3} **77.** 83.8 cm^3. **85.** 35.1°C. **91.** 26.4%.

Index

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